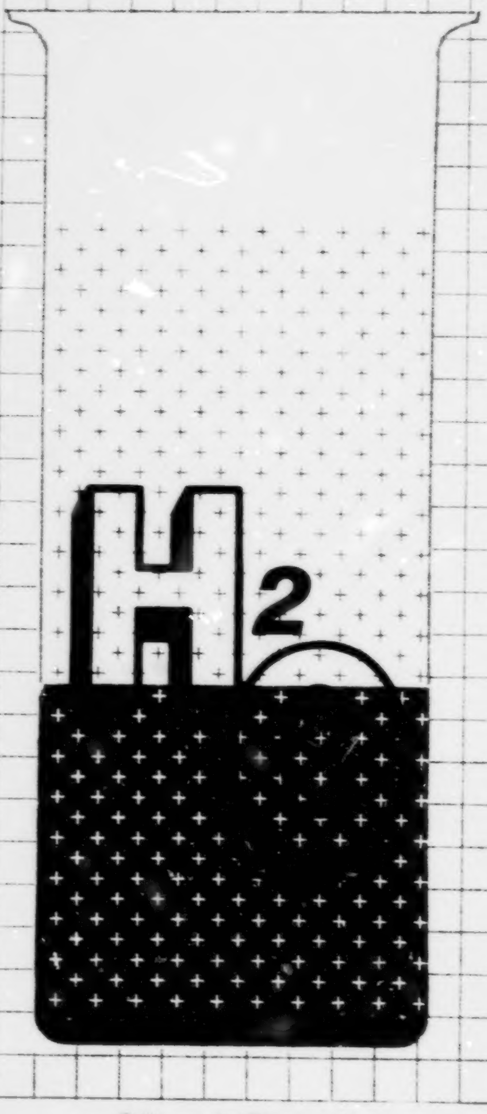
TORONTO'S DRINKING WATER

A CHEMICAL ASSESSMENT



City of Toronto
Department of Public Health

CITY OF TORONTO
DEPARTMENT OF PUBLIC HEALTH

April 5, 1984

To: Local Board of Health

Subject: Toronto's Drinking Water

Origin: Local Board of Health, November 24, 1981
(c34hlth84048:168)

Comments:

At its meeting on November 24, 1981, the Local Board of Health had before it for consideration reports concerning Toronto's drinking water. The Board requested that the Department of Public Health prepare an in-depth report, in cooperation with members of Pollution Probe, City of Toronto Department of Public Works, and the Metropolitan Works Department, which would: (a) summarize current knowledge of the health effects of organic and heavy metal contaminants in drinking water; (b) review the need for and feasibility of upgrading the current purification system; and (c) report on the extent to which Toronto's sewage system is contributing to the contamination of Lake Ontario.

The concern at that time was "Is Toronto's drinking water safe?" I pointed out then and repeat now that Toronto does not have a high rate of gastro-intestinal or bladder cancer, and that our rate of congenital anomalies is remarkably low. In the study attached, we make rough comparisons of chemicals in Toronto's water with other jurisdictions in Canada and the United States and we find that Toronto water compares reasonably. Residents of Toronto can drink tap water with reasonable assurance it is not likely to cause harm or injury. There is no need to buy bottled water or to invest in purification devices.

Why, then, all the fuss?

In the first place, we have become increasingly aware of sources of chemical pollution in Lake Ontario. Secondly, advancing technology has given us new tools and new ways of looking at risk. Much of this is controversial and requires public debate. Finally, new treatment technologies hold promise for even purer water.

We know too little. Many of our recommendations call for testing or more research. For example, Metro Works Department carries out very extensive testing at the plant. Municipalities do little testing at the tap.

Our knowledge of trihalomethane formation in the Toronto system is incomplete. Decisions about major capital investment cannot be made in the absence of good comparative data on the performance of other systems. The Toronto Area Watershed Management Study

(TAWMS) holds promise of identifying pollution sources affecting the Metro Toronto waterfront and hence, potentially, intake water quality.

Throughout this study we have used maximum ever concentrations reported by Metro Works Department. Some of these, such as the high mercury levels may be laboratory errors. Some may have occurred only once in thirty or forty testings, some at only one plant. They represent a "worst case" situation. It is not appropriate to use these figures to generate human exposure estimates. We used these findings for consistency, to avoid having to use enormous numbers of tables, and to avoid the possibly misleading use of averages.

Setting standards for drinking water quality leads us into an area of scientific controversy and debate. Classical epidemiologic studies do not always detect slight risks, yet slight risks may be important when large numbers of people are exposed. The applicability of laboratory tests to humans is often challenged. Even the definition of what substances are carcinogens is not unchallenged.

We believe Canadian standards for drinking water quality should be reviewed using a risk assessment method similar to the procedures of the Environmental Protection Agency in the U.S.A., including the use of public hearings.

Finally, there is great interest in ozonation and activated carbon filtration as alternate strategies or additions in water treatment. While the most desirable strategy is to reduce the contamination of Lake Ontario at the source, it is prudent to consider these other treatment methods.

I recognize that Local Board of Health members have received this report too late to comment on April 24th. This delay was necessitated by a wish to avoid the highly emotional and confrontational atmosphere which surrounded previous reports on Toronto's water quality. There are important issues here which deserve reasoned debate. I support the recommendations of this report but suggest deferral of Board discussion to permit members adequate time to study them.

Recommendation:

That the Local Board of Health adopt the recommendations contained on pp.11-15 of the attached report.

ASM:sa
Attach.

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TORONTO'S DRINKING WATER

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April, 1984

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ACKNOWLEDGEMENTS

We would like to express our thanks to the many people and agencies who assisted us in the development of this report. These include the Water Supply and Water Pollution Control Divisions of the Metro Works Department; Doug Doherty of the Public Works Department; Joanna Kidd and Kai Millyard of Pollution Probe; Toby Vigod of the Canadian Environmental Law Association; George Missingham and Steve Salbach of the Ontario Ministry of the Environment; and Roch Khazen of the Ontario Ministry of Health. Our thanks also go to many of our colleagues in the Department of Public Health, including Fred Goettler, Nancy Day, Linda Rosenbaum, Ron Labonte, Trevor Hancock and Brian Gibson, for their helpful comments and support.

We are extremely grateful to four reviewers who took the time to read and comment on a draft of this report: Don Wigle of Health and Welfare Canada; Doug Hallett and Rick Findlay of Environment Canada; and Andrew Benedek of Zenon Environmental Inc.

While we have seriously considered all comments made to us, the opinions and recommendations in this report are those of the City of Toronto's Medical Officer of Health and the Department of Public Health. Our acknowledgement of the assistance and review of individuals and agencies does not necessarily imply endorsement of this report by those individuals or agencies.

SUMMARY

This report is intended to assess whether the consumption of Toronto's drinking water is likely to be a health hazard or not, and to evaluate alternative drinking water treatment systems from a public health perspective. This has been done by discussing possible sources of chemical contaminants to our drinking water, as well as the potential health effects of chemicals that have been identified in Toronto's water. In the light of our findings, the report goes on to assess several alternative filtration and disinfection systems that could be considered for use in Toronto.

Lake Ontario, the source of Toronto's drinking water, is the smallest in area of the Great Lakes and like all the Great Lakes, it has been seriously contaminated by human activity. Through the IJC (International Joint Commission), both the Canadian and U.S. governments are committed to improving the Great Lakes water quality, but progress has been slow partly because of a lack of coordination between the many jurisdictions involved.

Monitoring has shown the presence of more than 800 chemicals in the Great Lakes ecosystem. Concentrations of many organochlorines in fish and animals have been decreasing, but recent data suggest some chemical concentrations may be increasing again. Many species also contain heavy metals, but concentration trends over time are difficult to determine. Lake Ontario's sediments also contain organic and inorganic chemicals as a result of human activities. Data are not comprehensive enough to detect changes in concentrations.

There are many sources of chemical pollutants to Lake Ontario which could affect Toronto's drinking water. Probably the best known is the Niagara River. Sources of contaminants to the river include direct industrial and municipal discharges as well as leaking waste disposal sites and groundwater. Industrial discharges are poorly regulated, and municipal wastewater treatment plants still contribute large amounts of chemicals. This is especially true of the Niagara Falls, N.Y. wastewater treatment plant, which has not been fully operational since its construction in 1978. Leaking waste disposal sites also release chemicals to the river. There are four main sites of concern: Love Canal, Hyde Park, 102nd Street and S Area. Progress on the remedial work is agonizingly slow. This is because of a lack of agreement about what should be done and who should do it. Recent evidence suggests that groundwater contaminated by leaking waste disposal sites is migrating toward the Niagara River. If this is occurring on a large scale, the chemical loadings to the Niagara River from groundwater could be greater than those from point sources of contaminants.

Other sources that may affect drinking water quality include the Don and Humber Rivers and Mimico Creek. These watersheds are being studied by the Ministry of the Environment, and data show the presence of organic and inorganic chemicals, sometimes equalling or exceeding their respective Provincial Water Quality Objectives. It is hoped that this study will contribute to the development of abatement strategies for reducing chemical contamination in the Toronto watersheds.

Toronto's sewage system is probably also a major source of contaminants along the waterfront. Neither storm nor combined sewer overflows are routinely monitored for chemicals, so it is impossible to assess how much untreated chemical effluent is entering Lake Ontario. In addition, the treatment process itself was not designed to treat such effluents, and it is not known how the process affects them. Sewage effluent is routinely monitored for some metals, but not organic chemicals. At present we do not have sufficient data to assess the extent to which the sewage system is contaminating Lake Ontario.

Lakefilling and dredging is another local source of pollutants about which little is known. Dredgeate and fill materials have been shown to be contaminated with heavy metals and organics, such as PCBs. Dredging inevitably resuspends some of these and lakefilling deposits more contaminated material into the lake. Although there is no evidence that these activities are affecting the quality of Toronto's drinking water at present, the potential for contamination exists.

These, and other sources may influence the chemical quality of Toronto's drinking water. The filtration and disinfection processes also add chemicals to the water supply. One of these, chlorine, reacts with natural substances in water to form trihalomethanes, which are consistently detected in Toronto's drinking water. Trihalomethanes are mutagenic in the Ames test (except for chloroform, which is an animal carcinogen) and should therefore be regarded as potential human carcinogens.

It is now well established that chlorination increases the mutagenicity of drinking water, although only a fraction of this increase is due to trihalomethane formation. The majority is due to the formation of unidentified non-volatile mutagens. One study of Great Lakes water showed that chlorinated water was more mutagenic than raw lake water by factors of between 2-10 times. This suggests that chlorination is the largest single source of potentially hazardous chemicals to drinking water. However, in making this statement we would like to acknowledge the tremendous public health benefits that have resulted from the use of chlorine. We are therefore recommending that possible alternatives to chlorination (and existing filtration methods) be studied by federal (Health and Welfare Canada), provincial

(Ontario Ministry of the Environment) and municipal (Metropolitan Toronto Works Department and Medical Officers of Health) authorities.

As well as trihalomethanes, many other organic and inorganic chemicals have been infrequently detected in Toronto's water. In total, 83 chemicals have been identified since 1971. Of these, 28 were inorganic and 55 were organic, although inorganics are detected more frequently. Seven are human carcinogens and 23 are potential human carcinogens.

The existing filtration and disinfection system was not designed to remove organic or inorganic chemicals from drinking water, but it does affect them. Concentrations are affected unpredictably, some increase, some decrease, and some stay the same. There is also variability in the behaviour of individual chemicals.

The quality of Toronto's drinking water is comparable with that in many U.S. cities. It is more difficult to do a comparison with Canadian drinking water, because there has not been a comprehensive national survey of inorganics and organics in Canadian drinking waters. Surveys of drinking water quality from around the Great Lakes and of trihalomethane concentrations, suggest that Toronto's water is of approximately the same quality as many other Canadian municipalities.

Water distribution systems can also contribute chemicals to drinking water. Toronto's system is approximately 100 years old, but it is still structurally sound. This is because corrosion is not a very serious problem. Recently, some plastic pipes have been installed, and there is evidence that chemicals can leach from them into drinking water.

Samples of drinking water used for chemical analyses are usually taken at the filtration plants, rather than at the tap. If samples from each are compared, it can be seen that concentrations of some inorganics are higher in tap water. More significantly, in the few samples tested, concentrations of trihalomethanes were higher at the tap than at the filtration plants. This suggests trihalomethane formation is occurring in the distribution system.

The recent emphasis on the quality of drinking water has resulted in an increased use of alternatives to municipally supplied and treated water. Bottled waters are seen as one alternative to tap water, but they are not chemically analyzed on a regular basis, like municipally supplied water. Chemical analyses, conducted by the Department of Public Health and Metro Works Department, showed that bottled waters do not necessarily contain fewer chemicals, or at lower concentrations than tap water (excepting trihalomethanes). Water filters, another alternative, can be colonized by bacteria which may be pathogenic. There are doubts about the long term efficiency of such filters in removing chemicals. Water distillers can now also be purchased in Toronto, but distilling does not necessarily remove all organic chemicals and may in fact concentrate some. In addition, distilled water is felt by many to have a flat and unpleasant taste.

Health hazards that could be associated with drinking water are assessed by three main methods: epidemiology, animal studies, and carcinogenesis/mutagenesis assays. Each has advantages and disadvantages, but when used in combination the results are more likely to provide an accurate estimate of human health effects.

These methods mentioned above assess the hazards from exposure to individual chemicals, yet we are usually exposed to many chemicals through a variety of sources (e.g., food and water). Chemicals can interact synergistically, additively or antagonistically and it is unlikely that science will ever be able to quantify all the risks. Given this situation, we must look for new ways to improve our assessment of hazards. One possibility is the use of biological methods, such as the Ames test for mutagenicity. This type of test can assess the hazards associated with exposure to one or a mixture of chemicals.

Once the health hazards associated with chemical exposure have been investigated, this information can be used to derive standards for drinking water. There are two ways of evaluating data: establishing "no observed effects levels" and risk levels.

A "no observed effects level" is determined by identifying a concentration below which there are no observed adverse health effects in animals. This concentration is then extrapolated to human health, allowing for such factors as body weight, the average daily consumption of drinking water and how good the data are. A safety factor is usually incorporated, although not necessarily the same factor is used for all chemicals. The use of "no observed effects levels" implies that threshold levels of chemicals exist, below which there are no risks of health effects developing. While thresholds have been demonstrated for some non-cancer health effects, it is not generally accepted that they exist for cancers.

In contrast, risk levels are defined as the mortality or morbidity in a given population resulting from exposure to a particular chemical at a particular concentration. It is often necessary to extrapolate to low exposure levels and large populations, because most exposures resulting in observed health effects are relatively large, and the human population is often much larger than the experimental animal population. Extrapolation is made much more accurate by quantifying the health effects resulting from many exposure levels, although it is often difficult to estimate the risk of health effects at very low exposures. Estimates of risk levels are therefore subject to wide variations. After such an "exposure vs. health risks" table has been constructed, it is necessary to decide what level of health risk is acceptable, so that an exposure standard can be set. This decision is a matter of value judgement, rather than scientific fact. Even the term "acceptable risk" implies the purposeful acceptance of a risk (such as the presence of chemicals in drinking water) by those exposed to it. But most decisions about what risks are acceptable in Canada are not usually made in public. We are therefore recommending that public participation should be encouraged when drinking water, and other environmental standards, are being set.

At present, health effects are not the only criteria used to set drinking water standards. For example, in the Guidelines for Canadian Drinking Water Quality, 1978, most "objective concentration guidelines" are set at current detection levels, and in the U.S. the "maximum contaminant level" for trihalomethanes is set at "a feasible level achievable with water treatment technology". The Department of Public Health proposes that the primary determinants of drinking water standards should be the protection of the public's health and the supply of aesthetically acceptable water.

The Canadian drinking water guidelines are set using "no observed effects levels" for both carcinogens and non-carcinogens (except for trihalomethanes and nitrilotriacetic acid). This results in wide variations in the levels of risk when the guidelines are examined using the risk levels method. In addition, many regulatory agencies now use the risk levels method of setting standards for carcinogens because it is not generally accepted that there are threshold levels of chemicals below which there are no risks of health effects developing. We are recommending that this approach should also be used to set standards for carcinogenic chemicals in Canadian drinking water.

Other contentious issues around the Canadian drinking water guidelines are that they only cover a limited number of chemicals, and they are not legally enforceable. The Department of Public Health is recommending that additional chemicals be considered for inclusion, and that the desirability of enforceable standards be examined. Health and Welfare Canada is currently reviewing the existing guidelines.

In addition to the problems associated with the guidelines themselves, there are also vast uncertainties about the health effects of many chemicals that have been detected in drinking water. The report outlines those that are known, but our knowledge is very incomplete. Little is known about possible health hazards from the ingestion of chemicals detected infrequently and at low concentrations. Moreover, our knowledge of the combined effects of chemicals is almost non-existent. Many infrequently identified chemicals have been detected in parts per trillion, but we cannot dismiss these seemingly low concentrations as being insignificant. We simply do not know. Therefore, the Department of Public Health is advocating that a cautious approach be adopted to the ingestion of chemicals through drinking water. This lack of knowledge is a source of frustration for everyone, but probably most of all to the ordinary citizen who hears conflicting opinions from all sides.

These difficulties are aggravated by the widening gap between our ability to detect chemicals and our knowledge to interpret detected levels in terms of human health effects. Public officials report new data to the public, but if their significance cannot be explained, the possibility of generating alarm adds a new dimension to their responsibility. Different jurisdictions add to this problem by issuing different guidelines or standards. The public's interpretation is that one jurisdiction is saying that a given chemical concentration is safe, while another is saying it is unsafe. This severely threatens the credibility of government agencies in the public's eyes.

Another problem is the continuing imprecise use of the term 'safe'. Safe may mean free from danger, as in "A person once infected with small-pox is safe from having it a second time". Safe may also mean not likely to cause harm or injury, as Florence Nightingale used the term: "The safest atmosphere of all for a patient is a good fire and an open window".

We confront daily questions using the latter sense, e.g., is air travel safe? Will my child be safe playing minor hockey? What we are seeking is a statement of the degree of risk associated with the activity, or an assurance that all reasonable steps have been taken to minimize a known risk.

At the turn of the century, Toronto's water was unsafe because of bacterial contamination. Chlorination dramatically reduced that risk, but introduced a new, very much smaller risk, the production of mutagens and carcinogens from the interaction of chlorine with organic material in the water. As each new level of safety is reached, we seek further refinement. Helmets for children playing hockey were improved by the addition of protective eye shields. In the case of municipally supplied drinking water, there is a special obligation to ensure that all reasonable steps have been taken to minimize risk since the public has limited alternatives. This report is an attempt to explore the necessity and feasibility of improving the already good quality of Toronto's water, and to involve the public in the process.

From the discussion above, it can be seen that it is impossible to assess the extent of health effects that could be attributed to Toronto's drinking water accurately, however, data from the U.S.

Environmental Protection Agency (EPA) can be used to derive a tentative estimate of the increased cancer incidence due to trihalomethanes in the City of Toronto's drinking water. This suggests that one cancer every three years may be due to trihalomethane ingestion. This is a minute fraction of the cancer incidence in Toronto. We would like to stress that this estimate cannot be scientifically supported. It is merely an estimate extrapolated from animal data and does not represent known cases of cancer. The use of this estimate does not imply that consumption of Toronto's water causes cancer, however it is intended to stress that there are risks associated with drinking water. Indeed, our epidemiological study failed to demonstrate any correlation between drinking water mutagenicity (as measured in the Ames test), three cancer sites that have previously been associated with the presence of chemicals in drinking water, and adverse pregnancy outcomes.

Discussion of the health effects associated with hazardous chemicals in drinking water has concentrated on cancer, mutagenesis, teratogenesis, birth defects and some short-term effects, such as disturbances of the central nervous system. This is because these are the types of health effects that have been studied. We should not preclude the possibility of the occurrence of other health effects which have not yet been studied in such detail. Although this report concentrates on known health effects this should not be seen as implying that these are the only possible effects.

In view of uncertainties regarding the effectiveness of conventional water treatment methods, and the lack of knowledge about the hazards associated with the presence of chemicals in drinking water, we are recommending that alternatives to conventional treatment methods be investigated at both field and research levels. There are several alternatives to both disinfection and filtration. Alternative disinfection methods include the use of ozone, and chlorine dioxide. The main alternative to conventional filtration is the use of granular activated carbon (GAC).

Ozone has been used throughout Europe for many years, and more recently in Montreal. It is popular due to its excellent biocidal abilities and effectiveness in controlling tastes and odours. Recent research has shown that ozone may be effective also at eliminating organic precursors to trihalomethane formation. Little is known about organic compounds that are formed in the process of ozonation. Those that have been identified (e.g., aldehydes, ketones, and carboxylic acids) are relatively biodegradable and are not regarded as being hazardous to human health.

The greatest disadvantage of ozone is that it does not provide residual disinfection. Unless ozone is used in conjunction with another disinfectant, microorganisms are likely to grow in the distribution system, particularly if finished water has a high dissolved organic carbon content and a long residence time in the system before it reaches the tap.

Chlorine dioxide is a powerful chemical oxidant widely used for primary and residual disinfection of water supplies in Europe. In the United States and Canada chlorine dioxide is used infrequently for taste and odour control. The U.S. Environmental Protection Agency recommends a maximum dosage of 1 mg/L of chlorine dioxide for drinking water treatment.

Unlike chlorine, chlorine dioxide does not form trihalomethanes when combined with organic matter. Little research has been undertaken concerning organic by-products of chlorine dioxide. Thus, work on health effects has been limited to studies of chlorine dioxide itself and its most common reaction products, chlorite and chlorate. Toxicological research demonstrates conclusively that these substances are blood oxidizing agents which impair the body's oxygen carrying ability and can lead to hemolytic anemia. Additionally, chlorine dioxide treated water has been shown to possess mutagenic properties. Preliminary epidemiological research has failed to demonstrate adverse effects of drinking chlorine dioxide treated water for up to three months among healthy adults. Both epidemiological and toxicological research suggests, however, that certain groups may be more sensitive to blood oxidizing effects of chlorine dioxide, namely individuals who are deficient in glucose-6-phosphate dehydrogenase, and infants. There is some evidence that newborns are adversely affected by chlorine dioxide treated water. Further work is required in this area and into chronic health effects of exposure to chlorine dioxide, chlorite and chlorate.

The practice of adding ammonia to chlorinated water supplies for taste and odour control, thereby producing chloramines, is common in North America. This practice is followed in Metro Toronto. Chloramines are weaker disinfectants than chlorine, but combined chlorine has the advantage of being more stable than free chlorine and thus persists longer as a residual disinfectant in distribution systems. Research shows that chloramines are less likely than free chlorine to react with organic compounds and form trihalomethanes. Unfortunately, little else is known about reaction products of chloramines with other compounds in water.

Information on health effects of chloramines also is limited. Some evidence indicates that monochloramine is a red blood cell oxidizer for humans, but this finding was not replicated in studies with animals. Monochloramine also is a weak bacterial mutagen, and research is currently underway on the long-term carcinogenesis bioassays of both mono- and dichloramine. At present, there are no recommended maximum concentrations of chloramine in finished water.

Activated carbon has become increasingly popular as a potential alternative to conventional treatment approaches.

Research over the past decade in the U.S. and in Europe has shown that activated carbon in its granular form is an effective chemical filter medium for many organic chemicals, and possibly certain inorganics (iron, mercury, chromium). One disadvantage of granular activated carbon is that it becomes saturated and loses its effectiveness over time. When used in combination with ozone, however, it appears that the life of carbon beds can be extended significantly.

Activated carbon does not generate contaminants by forming by-products with chemical compounds. Because of its finite surface area and variable adsorption qualities of chemical compounds, not all compounds passing through a carbon bed are necessarily adsorbed on the carbon surface. Occasionally organic chemicals have been found in granular activated carbon effluents in concentrations exceeding influent levels. Whether these instances are due to competitive adsorption or variations in influent composition is unknown. Much of the research on activated carbon treatment effects has used grouped measures of organics rather than measuring individual organic compounds. Thus, future research efforts should seek to identify specific compounds that are of particular concern for health reasons.

It is possible, though unlikely, that pathogenic microorganisms colonized on carbon beds are sloughed off into finished water. Research on mutagenic activity of water treated with activated carbon indicates that rather than introducing contaminants into treated water, granular activated carbon removes them, at least those that are bacterial mutagens. In addition, pre-treatment with granular activated carbon reduces disinfection demand and increases disinfection efficiency. Research into microbial composition of granular activated carbon treated water has found that the most common bacterial strain in effluents is Pseudomonas. No fecal indicators or enteric bacteria have been found.

In the U.S., where pilot testing of granular activated carbon and other treatment alternatives has been in progress for many years, the first full-scale treatment facilities are now being planned. In Canada, the first granular activated carbon pilot plant study is being planned by the Ontario Ministry of the Environment for the Niagara Region.

There is an abundance of evidence to indicate the effectiveness of alternatives to conventional treatment. In the U.S. and in Europe there is a strong movement towards using granular activated carbon for chemical removal in conjunction with ozone for disinfection. From a public health perspective, this is a preferred treatment alternative. We believe that Canada, and Toronto in particular, should also investigate the effectiveness of such alternatives. A city of Toronto's international stature should be taking a leadership role in issues as critical as drinking water quality and treatment.

In summary, this study has been unable to demonstrate that the consumption of municipally supplied water has resulted in any observed health effects. However, an extrapolative experimental technique suggests that a minute fraction of the cancer incidence in Toronto may be associated with the ingestion of trihalomethanes in drinking water. This estimate could not be supported scientifically because the predicted increased incidence is so small. Moreover, this estimate does not imply that Toronto's water causes cancer, but it is intended to stress that there are risks. There are also many uncertainties about the health effects of the trace amounts of inorganic and organic chemicals that are infrequently detected in Toronto's drinking water. Acknowledging this lack of information, we are recommending that experimental alternatives to the existing filtration and disinfection system be investigated to determine whether effective removal of these trace chemicals is possible in Toronto, and whether suitable alternative disinfectants exist.

SUMMARY OF RECOMMENDATIONS

1. That the Commissioner of the New York State Department of Environmental Conservation be requested to review the basis for the SPDES (State Pollutant Discharge Elimination System) permits. Such a review should examine whether it is appropriate to include considerations of ambient contaminant concentrations in the Niagara River, chemical contaminants entering the river from non-point sources, and the water quality objectives of the Great Lakes Agreement, 1978, in discharge permits.

2. That the Commissioner of the New York State Department of Environmental Conservation be requested to encourage the regulation of more priority pollutants in all new and renewed SPDES permits.

3. That the Director of Utilities for the City of Niagara Falls, New York be requested to complete the necessary remedial work on its wastewater treatment plant as soon as possible.

4. That the Commissioner of the New York State Department of Environmental Conservation and the Administrator of the U.S.

Environmental Protection Agency be requested to consider the excavation and removal of contaminated materials as an alternative to in situ management of the leaking waste disposal sites most likely to contribute to the contamination of the Niagara River.

5. That the Commissioner of the New York State Department of Environmental Conservation and the Administrator of the U.S. Environmental Protection Agency be requested to consider the development of environmentally sound disposal options as a matter of utmost importance. This should include the development of programs to minimize the quantities of hazardous wastes produced, and to improve their quality wherever possible.

6. That the Commissioner of the New York State Department of Environmental Conservation and the Administrator of the U.S. Environmental Protection Agency be requested to investigate the extent and levels of the chemical contamination of groundwater in the Niagara and Erie County region, and to estimate the likely effects on water quality in the Niagara River and Lake Ontario.

7. That the Minister of the Environment for Ontario be requested to continue to work toward abatement strategies for the Toronto watersheds.

8. That the Commissioner of the Works Department, Metropolitan Toronto be requested to include computer modelling of the dispersion characteristics of the most significant chemicals (e.g., chlorine and heavy metals) identified in the Main treatment plant effluent, in the planning process for the new outfall pipe.

9. That the Commissioner of the Public Works Department, City of Toronto, be requested to undertake a comprehensive chemical analysis of all storm sewer outfalls and combined sewer overflows at least once a year, using the U.S. Environmental Protection Agency's list of priority pollutants as a basis.

10. That the Commissioner of the Works Department, Metropolitan Toronto, be requested to chemically analyze effluent samples from all four Metropolitan Toronto sewage treatment plants at least once a year using the U.S. Environmental Protection Agency's list of priority pollutants as a basis.

11. That the Commissioner of the Works Department, Metropolitan Toronto, and the Commissioner of the Public Works Department, City of Toronto, be requested to integrate the programs of chemical analysis mentioned in recommendations (9) and (10)

above, by using the same list of chemicals, and standardized sample collection and analytical procedures.

12. That the Minister of the Environment for Ontario be requested to define, or have defined, and make public, "zones of non-compliance" with the Provincial Water Quality Objectives for point sources of contaminants to the Toronto waterfront.

13. That the Minister of the Environment for Ontario be requested to develop a consistent year-round monitoring program for the Toronto waterfront, to be based on an assessment of the relative contributions of all point sources of chemical contaminants.

14. That the Chairmen of the Great Lakes Science Advisory Board and the Water Quality Board of the International Joint Commission be requested to investigate the atmospheric deposition of organic and inorganic chemicals into Lake Ontario to the fullest extent possible.

15. That the Minister of National Health and Welfare be requested to investigate the health effects of the non-volatile mutagenic fraction of chlorinated drinking water in animals to determine its carcinogenic potential.

16. That the Minister of National Health and Welfare be requested to initiate a research program to investigate possible alternatives to the use of chlorine as a drinking water disinfectant. This could also include an evaluation of alternatives to conventional filtration methods, such as granular activated carbon.

17. That the Commissioner of the Works Department, Metropolitan Toronto, be requested to identify any additional chemicals present in Toronto's drinking water at the most sensitive detection levels possible which are not included in regular analyses, by performing a complete gas chromatograph/mass spectrometer or electron capture scan on one set of drinking water samples in 1984.

18. That the Minister of National Health and Welfare and the Minister of the Environment (federal) be requested to undertake a national survey of organic and inorganic chemicals in Canadian drinking water.

19. That the Commissioner of Public Works, City of Toronto, be requested to investigate the extent of leaching of organic chemicals from plastic pipes and pipe sealants. Such a study should include the determination of actual concentrations in areas of the Toronto distribution system where plastic pipe is used.

20. That the Medical Officer of Health, in cooperation with the Commissioner of Public Works, City of Toronto, be requested to prepare a proposal for systematic testing for chemicals in tap water in the City of Toronto, and that other municipalities be encouraged to do the same.

21. The the Commissioner of Works, Metropolitan Toronto, be requested to study possible methods of reducing trihalomethane concentrations in the distribution system.

22. That the Minister of National Health and Welfare be requested to chemically analyze brands of bottled water sold in Canada, on a regular basis.

23. That the Minister of National Health and Welfare be requested to assess the chemical quality of brands of bottled water sold in Canada with the Guidelines for Canadian Drinking Water Quality, 1978, as well as with the bottled water regulations under the Food and Drug Act.

24. That the Minister of National Health and Welfare be requested to reconsider the policy of permitting the sale of tap filtration devices in Canada.

25. That the Minister of National Health and Welfare be urged to consider confining the use of the "no observed effects levels" method of standard setting to non-carcinogenic chemicals in drinking water.

26. That the Minister of National Health and Welfare be requested to recommend a zero level of exposure to carcinogenic chemicals, where possible. Where this is not possible, it is recommended that exposure levels to carcinogens should be set using risk levels, rather than "no observed effects levels".

27. That the Minister of National Health and Welfare be requested to develop a mechanism for encouraging public participation when setting drinking water and other environmental standards, by incorporating a time period for public review and public hearings before standards are finalized.

28. That the Minister of National Health and Welfare be requested to consider setting drinking water guidelines for a comprehensive range of organic chemicals. This could be based on the U.S. Environmental Protection Agency's list of priority pollutants.

29. That the Medical Officer of Health, City of Toronto, be requested to prepare a short report on the implications of mandatory drinking water standards for chemicals.

30. That the Minister of National Health and Welfare be requested to investigate the possible interactive multi-generational effects of long term exposure to chemicals in drinking water.

31. That the Minister of National Health and Welfare be requested to conduct animal studies on the possibility of such health effects as behavioural and psychological effects, suppression of the immune system and changes in fertility rates, and their relationship with the ingestion of hazardous chemicals, particularly through drinking water.

32. That the Minister of the Environment for Ontario be requested to consider initiating a comprehensive field study to evaluate alternative disinfection and filtration techniques, and report back to the Local Board of Health. Such a study could include evaluations of the effectiveness of ozone (as a disinfectant and in eliminating organics) and granular activated carbon. It is further recommended that combinations of alternative technologies (for example, granular activated carbon and ozone) and combinations of alternative and conventional technologies (for example, granular activated carbon and chlorine) be evaluated. It is also recommended that this study be undertaken in collaboration with the Metro Toronto Works Department, using Toronto's drinking water supply, and the results be analyzed in consultation with the Medical Officers of Health for Metropolitan Toronto.

1. TERMS OF REFERENCE AND INTRODUCTION

1.1 Terms of Reference

At its meeting on November 24, 1981 the Local Board of Health requested that the Department of Public Health prepare an in-depth report, in cooperation with members of Pollution Probe, City of Toronto Department of Public Works and the Metropolitan Toronto Works Department, which would:

a. summarize current knowledge of the health effects of organic and heavy metal contaminants in drinking water;

b. review the need for and feasibility of upgrading the current purification system; and

c. report on the extent to which Toronto's sewage system is contributing to the contamination of Lake Ontario.

The Medical Officer of Health is required by provincial legislation to protect the general public from potential and actual health hazards. Specifically, under the Public Health Act, 1980, s/he is required to abate 'nuisances' which are defined as "Any condition existing in a locality that is or may become injurious or dangerous to health or that prevents or may prevent or hinder in any manner the suppression of disease ...", and the particular "nuisances" mentioned in the Act include "any well, spring or other water supply that is injurious or dangerous to health" (sections 115 and 116; subsection c). Under the proposed Health Protection and Promotion Act, 1983, s/he is required to prevent, eliminate and decrease the effects of health hazards (section 10, subsection 1) and s/he "... may make examinations, investigations, tests and inquiries ..." (section 40; subsection 4) to that end.

The goals of this report are therefore to:

a) Assess whether there is, or is not a potential or actual hazard to health resulting from the consumption of Toronto's drinking water;

b) Determine the magnitude of the potential or actual health hazard, should such exist;

c) Review the health implications of alternatives to conventional filtration and disinfection techniques; and

d) On the basis of a. to c., above, recommend whether or not the existing water filtration and disinfection system should be upgraded.

In addition, a chemical analysis of various brands of bottled water was undertaken to assess their suitability as alternatives to municipally supplied water. Funds for this were approved by the Local Board of Health at its meeting of June 21, 1983 and a final report was presented to the Board on November 8, 1983.

1.2 Introduction

Water is essential for human life; a healthy person can only survive for about three days without it. Water constitutes between 50 and 75% of our body weight and approximately two litres a day should be consumed by adults. This quantity varies with climate and the level of activity. The consumption of water can result in internal exposure to disease-causing agents (e.g., bacteria) already present in the water. Therefore, to protect human health, drinking water should be as free from these agents as possible. This requirement has been recognized by the United Nations, who proclaimed the 1980's as the International Drinking Water Supply and Sanitation Decade.

A report on drinking water by the Department of Public Health is relevant for several reasons. Firstly, the publication of many articles and reports on the quality of Toronto's drinking water (most notably Pollution Probe's Toxics on Tap (1) and Drinking Water: Make It Safe! (2) has raised public awareness of this issue. Secondly, despite concerns expressed by the scientific and medical communities, and the general public, Lake Ontario and the Niagara River continue to be polluted. Concern has been heightened by uncertainties about the effectiveness of current water filtration practices which were not designed to remove chemicals from the water supply.

References to Section 1

1. Pollution Probe. Toxics on Tap: A report on the quality of Toronto drinking water. 1981, Toronto.

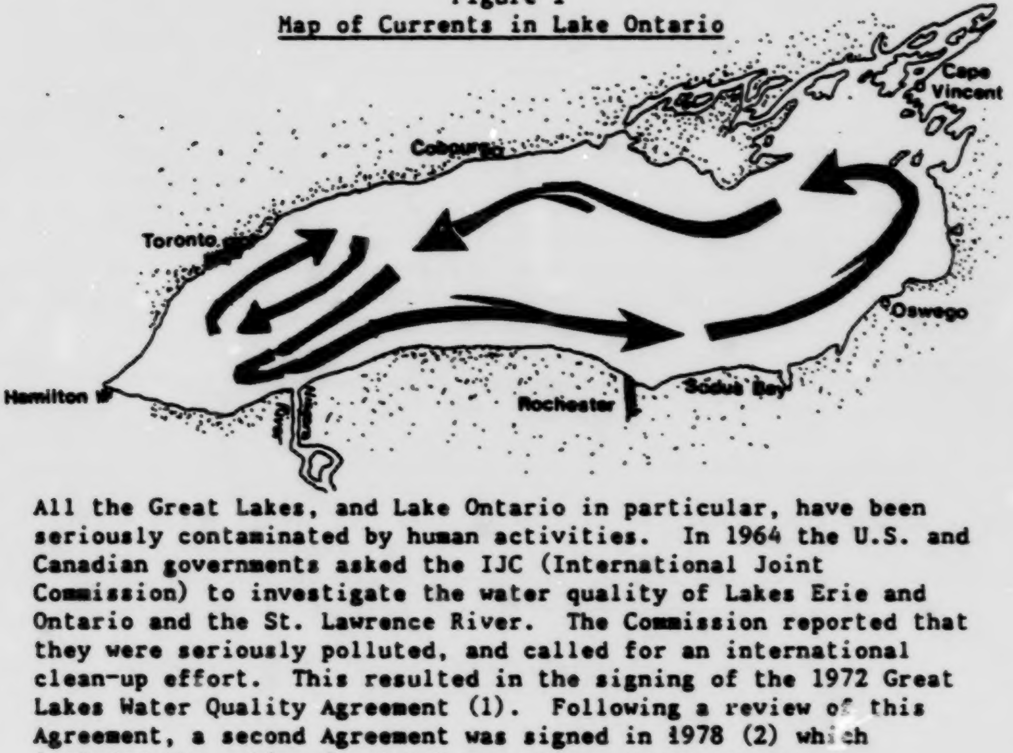
2. Pollution Probe. Drinking Water: Make It Safe!. 1983, Toronto.

2. LAKE ONTARIO

Lake Ontario is the smallest in area of the Great Lakes, being approximately 310 km long and 85 km wide, with an average depth of 86m. The major tributary is the Niagara River and the main outlet is the St. Lawrence River. Water is retained in Lake Ontario for approximately six years.

Currents depend on the prevailing meteorological conditions. For most of the year there is a general counter clockwise movement, with most of the flow from the Niagara River being carried east along the U.S. shoreline. Figure 1 shows one model of lake currents (14), however, nearshore Toronto currents are predominantly towards the west and parallel to the shoreline. Many chemicals are soluble at the concentrations at which they have been detected, so there are no real gradients across the lake. Gradients can be seen in the sediments.

Figure 1
Map of Currents in Lake Ontario



All the Great Lakes, and Lake Ontario in particular, have been seriously contaminated by human activities. In 1964 the U.S. and Canadian governments asked the IJC (International Joint Commission) to investigate the water quality of Lakes Erie and Ontario and the St. Lawrence River. The Commission reported that they were seriously polluted, and called for an international clean-up effort. This resulted in the signing of the 1972 Great Lakes Water Quality Agreement (1). Following a review of this Agreement, a second Agreement was signed in 1978 (2) which included the entire Great Lakes system and advocated an "ecosystem" approach (recognizing the complex interrelationships between plants, animals, water and humans) to management of the whole basin. The 1978 Agreement also recommended specific "objective concentrations" for persistent toxic chemicals, non-persistent toxic chemicals, microbiological organisms, radioactive elements, nutrients and physical substances and both parties (i.e., Canada and the U.S.) agreed that "the discharge of toxic substances in toxic amounts be prohibited and the discharge of any or all persistent toxic substances be virtually eliminated".

According to this Agreement, the U.S. and Canadian governments will conduct monitoring and research programs to identify:

a) trends in the concentrations of persistent toxics;

b) the impact of toxics on human health, plants and animals;

c) the sources of persistent toxics;

d) persistent toxics which have not been found before.

In addition, the IJC maintains lists of contaminants in the Great Lakes. Over 800 chemicals have now been identified in the ecosystem (3), although the potential health effects of many are unknown.

Some progress has been made toward reducing contamination, but it has been slow. One area that we still know very little about is how chemical concentrations are changing over time. Information is being gathered, but inconsistencies in monitoring programs have resulted in "snap shot" views of contamination rather than an overall picture.

Chemicals in Lake Ontario

All chemical contaminants will eventually pass through Lake Ontario (unless they are deposited, degraded, evaporated or metabolized), because it is the last lake before the St. Lawrence River. There are also many direct sources of chemicals, many of which originate in the Niagara and Erie County region. Hamilton and Toronto harbours are also significant sources and have been identified as "areas of concern" by the IJC (11).

Many chemicals are soluble at the concentrations at which they are found, so there are no real gradients across the lake. However, gradients can be seen in the sediments.

One group of chemicals in Lake Ontario which has received little attention is the polyaromatic hydrocarbons (PAHs). These chemicals are atmospherically deposited from many industrial sources such as waste incinerators and coking operations at iron and steel plants, and are well documented carcinogens. They are persistent in aquatic environments and can bioaccumulate in fatty tissue. This is unlikely to occur in mammals and birds because of an enzyme system capable of degrading them. This same system also converts many pro-carcinogenic (metabolically inactive carcinogens) PAHs to their active carcinogenic forms (5). Fish from Lake Erie and the upper Niagara River, where water and sediments contain elevated levels of PAHs, have been observed to have skin neoplasms. These were located near the mouth, so contaminants encountered during feeding may have been a causal agent (6). Recent research has shown that such neoplasms can be experimentally induced by painting extracts of polluted sediments onto the fish (15).

PAHs have been detected in both Lake Ontario (7,8) and Toronto's drinking water (9). Total PAH concentrations in Toronto's drinking water have varied from 0.016-0.15 ug/L, when they have been identified. There is no Health and Welfare guideline for PAHs; the World Health Organization (WHO) has recently published a new set of guidelines for chemicals in drinking water in which there is no recommended maximum concentration for PAHs. The IJC has recommended a limit of 0.01 ug/L for benzo-a-pyrene.

Biota

Lake Ontario fish contain concentrations of persistent organochlorines (such as total DDT residues) higher than those in fish from Lakes Superior, Erie and Huron. Fish samples collected between 1977 and 1981 showed a decline in concentrations of PCBs, dieldrin, mirex and DDT. But the decrease was not consistent from year to year and reached a plateau in 1979/80. Preliminary data for 1982 suggest that concentrations are increasing again. Concentrations of PCBs in lake trout, smelt and spottail shiners exceed the "objectives" of the Great Lakes Water Quality Agreement, 1978 (2), as do concentrations of DDT in lake trout. Some contained 2,3,7,8-TCDD (a dioxin) and mirex.

Concentrations of 2,3,7,8-TCDD in herring gull eggs taken from colonies on Lake Ontario are approximately five times those taken from colonies on the other Great Lakes (except for Saginaw Bay and the Detroit River). The presence of dioxin in eggs taken from four colonies on Lake Ontario suggests that fish (herring gulls' food source) have been contaminated lakewide. Analysis of eggs collected from 1976-79 indicates that levels of other organochlorines have been declining, but results from 1980 and 1981 show they are now rising, although they are still less than those reported for the mid-1970s (3).

2,3,7,8-TCDD has also been found in human tissues. Recently, Health and Welfare Canada reported that 21 human fatty tissue samples contained an average of 10 parts per trillion, and an additional sample contained 130 parts per trillion. The tissue donors lived in Kingston and Ottawa, and although on average

Kingston residents contained more 2,3,7,8-TCDD than Ottawa residents, the difference was not statistically significant (4).

Other human studies have analyzed fat and mother's milk, for a variety of organic residues such as organochlorines, organophosphates and pentachlorophenol. Levels of organochlorine residues declined rapidly in mother's milk following restriction of many such pesticides. This was not so for PCBs. Residues in fat are decreasing more slowly. The research showed that there were no significant differences between individuals living in different parts of Ontario, therefore it is unlikely that drinking water was a significant cause (12).

Lake Ontario fish and other biota also contain many heavy metals, including cadmium, copper, lead, zinc and mercury. It is unclear whether concentrations are increasing or decreasing over time. Mercury can be expected to decrease, as the only mercury-emitting processes in the Great Lakes have been discontinued.

Sediments

Concentrations of organic chemicals have also been studied in Lake Ontario sediments. Many chemicals tend to be deposited into one of the three main depositional basins: the Niagara, Mississauga, and Rochester basins, although high concentrations can also accumulate at the mouth of the contaminated tributaries.

Organochlorine residues are higher in depositional basins, although PCBs are relatively uniformly distributed. DDT and its metabolites are the most frequently detected organochlorines. Mirex has been shown to be present in sediments, the main sources being the Niagara River (from the Occidental Petroleum Company, previously the Hooker Chemicals and Plastics Corporation) and the Oswego River (from the Armstrong-Cork Company) (10).

Lake Ontario sediments also contain a variety of heavy metals, for example, concentrations of mercury are higher in the depositional basins and at the western end of the lake, than elsewhere (13).

One of the difficulties associated with tissue and sediment studies is that there is no central repository of samples and information. Recently, the IJC proposed that such a repository should be established. The Department of Public Health commends this proposal as it will facilitate research into contaminant problems in the Great Lakes.

References to Section 2

1. International Joint Commission *Great Lakes Water Quality Agreement 1972*. Windsor, Ontario: International Joint Commission, 1972.

2. International Joint Commission *Great Lakes Water Quality Agreement 1978*. Windsor, Ontario: International Joint Commission, 1978.

3. Great Lakes Water Quality Board *Report to the International Joint Commission 1983*. Windsor, Ontario: International Joint Commission, 1983.

4. Ryan, J.J. and Williams, D.T. "Analysis of human fat tissue from the Great Lakes area for 2,3,7,8-Tetrachlorodibenzo-p-dioxin and -furan residues". Presented at the American Chemical Society Meeting, September 1983, Washington, D.C.

5. Hallett, D.J. and Brecher, R.W. "Polynuclear aromatic hydrocarbons in the Great Lakes ecosystem". In Toxic Substances in the Great Lakes, ed. Noiagu, J., J. Wiley, Toronto, 1984.

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8. Great Lakes Water Quality Board *Report to the International Joint Commission 1976*. *Appendix E - Toxic Pollutants in the Lake Ontario Basin*. Windsor, Ontario: International Joint Commission, 1976.

9. Williams, D.T., Westmann, E.R., LeBel, G.L., Benoit, F.M. and Olson, R. 1982. *Determination of mutagenic potential and organic contaminants of Great Lakes drinking water".* *Chemosphere* *11* (3):263-276.

10. Van Hove Holdrinet, M., Frank, R., Thomas, R.L. and Hetting, L.J. 1978. "Mirex in the sediments of Lake Ontario". *Journal of Great Lakes Research* *4*:69-74.

11. Great Lakes Water Quality Board *Report to the International Joint Commission 1981 (Appendix)*. Windsor, Ontario: International Joint Commission, 1981.

12. Frank, R. University of Guelph. Interview, February 1984.

13. Thomas, R.L. 1972. "The distribution of mercury in the sediments of Lake Ontario". Canadian Journal of Earth Sciences. 9:636-651.

14. Pickett, R.L. and Bermick, S. 1977. "Observed resultant circulation of Lake Ontario". Limnology and Oceanography 22:1071-1076.

15. Black, J. 1983. "Field and Laboratory Studies of Environmental Carcinogenesis in Niagara River Fish", Journal of Great Lakos Research 9:326-336.

3. SOURCES OF CHEMICAL CONTAMINANTS WHICH COULD AFFECT TORONTO'S DRINKING WATER

The main tributary to Lake Ontario is the Niagara River, contributing 83% of the inflow to the lake (1). There are also several point sources of contaminants which influence the water quality along the Toronto waterfront. These are the Don and Humber Rivers, Mimico Creek, the Main sewage treatment plant, the Humber sewage treatment plant and the storm and combined sewer overflows. There are also non-point sources of pollution, such as precipitation and agricultural run-off.

3.1 The Niagara River

Since the beginning of this century the Niagara region has been highly industrialized, particularly on the U.S. side. This is because of its proximity to sources of cheap power and water. But the use and manufacture of chemicals has led to significant environmental degradation of the Niagara River and surrounding area. Recent problems have included bacterial contamination and high concentrations of phosphorus, iron and chloride. Some of these have been reduced in the last decade, but now hazardous organic chemicals are the focus of attention. Their presence has become a serious problem, mainly because of concerns about the safety of drinking water drawn from the river and adjacent lake.

The Niagara River and its problems have been the subject of many studies and reports (for example, see references 2, 3, 4, 5, 6).

Industrial Point Sources

There are many more point sources on the U.S. side of the river than on the Canadian side (see Table 1). On the U.S. side, about 12 municipal wastewater treatment plants and 90 industrial facilities have permits issued by New York State to discharge their effluents (over 250 million gallons per day - MGD) into the river or its immediate tributaries. Many other industrial facilities (over 300) discharge to municipal wastewater treatment plants, which in turn discharge to the river.

The permit system is intended to control the entry of contaminants to the Niagara River. Maximum levels for contaminants are set using the "waste load allocation plan". This plan divides the river into sectors and a tolerable total waste loading is calculated for each sector. However, ambient contaminant concentrations are not taken into account, and neither are contaminants entering the river from non-point sources, such as groundwater infiltration. Also, although the U.S. is a party to the 1978 Great Lakes Agreement, the water quality "objectives" specified in the Agreement are not always used to derive contaminant concentrations in discharge permits. Consequently, the objectives are sometimes exceeded in the Niagara River. It is therefore recommended that the Commissioner of the New York State Department of Environmental Conservation be requested to review the basis for the SPDES (State Pollutant Discharge Elimination System) discharge permits. Such a review should examine whether it is appropriate to include considerations of ambient contaminant concentrations, chemical contaminants entering the Niagara River from non-point sources, and the water quality objectives of the Great Lakes Agreement, 1978, in discharge permits.

Few of the permits issued in the past regulated the discharge of organic chemicals. Instead, they focussed on conventional influences such as pH, temperature, suspended solids, oil and grease, and some metals. A report prepared by the New York Public Interest Research Group (NYPIRG) (2), showed that more than 65% of the regulated industries used, stored, or manufactured synthetic organic chemicals. It is therefore recommended that the system be expanded to cover more of the U.S. Environmental Protection Agency's priority pollutants. There is some evidence that this is occurring (e.g., SCA Chemical Services' permit) and this is to be commended.

Also, discharge permits have been issued in the absence of independent data identifying the specific components in discharges, so that the responsible agency (the Department of Environmental Conservation) has relied on information submitted by the applicants. Similarly, the DEC has relied on submitted monitoring data to determine whether the dischargers are in compliance with their permits. However, a recent survey by the DEC showed that 89% of the industries with discharge permits were in compliance, although only 48% of the municipal wastewater plants were (9).

In Ontario there is no system for directly regulating discharges to the Niagara River. Instead they are regulated indirectly through Certificates of Approval, under the Environmental Protection Act.

Municipal Point Sources

Of the twelve U.S. municipal wastewater treatment plants, four are major point sources of contaminants to the river. These are the Buffalo Sewer Authority, the City of North Tonawanda, the City of Niagara Falls and the Town of Tonawanda. Based on U.S. Environmental Protection Agency (EPA) monitoring in 1981, these four plants discharge about 328 lbs. (149 kg) of organic priority pollutants (i.e., on the U.S. EPA priority pollutants list), 525 lbs. (239 kg) of phenols and 566 lbs. (257 kg) of heavy metals each day (22).

On the U.S. side, the majority of the organic priority pollutants and almost all the phenols are discharged by the City of Niagara Falls plant. Since 1978, wastewater has received primary (settling) treatment only, because after the construction of the plant the activated carbon beds (which provide secondary treatment) failed. Reconstruction has been delayed with consequent excessive discharges to the river. It is recommended that the City of Niagara Falls, N.Y. complete the necessary remedial work on its wastewater (sewage) treatment plant as soon as possible.

In contrast, there are only three sewage treatment plants on the Canadian side of the river (see Table 1). A survey conducted in 1981 of industrial and municipal point sources showed a total discharge of about 23 lbs. (10.5 kg.) per day of organic priority pollutants and 156 lbs. (71 kg.) per day of heavy metals. Thus the organic priority pollutants from point sources are less than 3% of the U.S. loadings and heavy metals are about 13% of the U.S. load (22). More detailed data on Canadian sources should be available later in 1984, as part of the Niagara River Toxics Committee report.

Table 1

A Comparison of U.S. and Canadian Source Loadings to the Niagara River *

	U.S.	Canadian
Number of municipal sources	12	3
Number of industrial point sources	89	12
Number of hazardous waste sites	155	12
Total effluent flow from point sources (m^3 per day)	1499×10^3	236×10^3
Approximate weight of organic priority pollutants discharged per day (kg) from point sources	403	10
Approximate weight of metals discharged per day (kg) from point sources	567	71

* Compiled from data in references 5 and 22.

Hazardous Waste Disposal Sites

In 1979 a New York State report (20) identified 215 hazardous chemical disposal sites in the Niagara and Erie County area, and of these 155 are within 3 miles of the Niagara River. At least four sites (Love Canal, Hyde Park, S Area and 102nd Street) are suspected to have leaked, or be leaking, contaminants into the river.

Love Canal

From 1942 to 1952, the Hooker Chemicals and Plastics Company disposed of a wide variety of chemical wastes at Love Canal. Approximately 21,800 tons of chemicals are buried there. In 1953, part of the site was sold to the City of Niagara Falls Board of Education, which built an elementary school on it, but as early as 1938, private homes were constructed near the canal. Many chemicals were transported by migrating water, and were drawn into the basement walls. Some of this contaminated water was pumped into the storm sewer system which discharged into the Niagara River. Chlorinated organic chemicals were identified in the basement air of these homes, and the ambient air contained chemical concentrations approximately 80 times those in downtown Niagara Falls. Hundreds of these homes have now been demolished.

Evidence of a significant excess of miscarriages near the canal and other health findings led the N.Y. State Commissioner of Health to declare Love Canal an official emergency in 1978. The U.S. EPA has also been involved in health effects research. They originally reported that residents of Love Canal had a higher frequency of chromosome breaks in their cells than a control group, however, this research has been disputed by many, including the EPA itself.

Since 1978 most of the residents have been evacuated and the area fenced off. Although the EPA recently published a report stating that it was safe for the residents to return, few, if any, have done so. The site continues to be the subject of considerable investigation. Leachate is collected and allowed to settle, and the liquid is disposed of to the municipal wastewater system following treatment through activated carbon beds. These clean-up activities are being paid for by the U.S. Superfund. There are plans to dredge the creek this summer (1984), and the storm sewers under the site, which are known to be contaminated with dioxins, have been isolated from the Niagara River. The Love Canal site is still the subject of many private and public lawsuits.

S Area

S Area is located on land reclaimed from the Niagara River belonging to the Occidental Petroleum Company (formerly Hooker Chemicals and Plastics Company). It was used as a disposal site from 1947 to 1975, even though it is only about 200 metres from the Niagara River.

The site contains approximately 63,000 tons of chemicals including the following: organic phosphates, acid chlorides, phenol tars, trichlorophenol, benzyl chloride, C-56 (hexachlorocyclopentadiene), chlorobenzenes, and mirex as well as many others. Leaching to the river has already occurred because of the high water tables and porous nature of the fill used.

S Area has been the subject of litigation for the last three years and recently a settlement was reached in which Occidental will spend at least $30 million to clean up the site. The settlement calls for physical containment of the site, an approach that Environment Canada has found unacceptable.

102nd Street

The 102nd Street waste disposal site belongs to both the Occidental Petroleum Company and to the Olin Corporation. It was used from (approximately) 1943 to 1971, and approximately 89,000 tons of chemical wastes are buried there. The following wastes are known to be buried there: organic phosphates, sodium hypophosphate, inorganic phosphates, BHCs (including lindane), and chlorobenzenes.

This site is located adjacent to the Love Canal and is bounded by the Niagara River. The water table is very high and fluctuates with the level of the river, therefore, it is extremely likely that leached material has entered the river. In 1970, the U.S. Army Corps of Engineers issued an order to Hooker Chemicals and Plastics Company to cease operations, cover the site with clay, and erect a retaining wall to prevent erosion of the site to the river.

Relatively little hydrogeological research has been done at this site. It has not received as much attention as the other sites because it is located in a sparsely populated area, but its potential for contaminating drinking water is high. Litigation for the clean-up of this site has not yet started because of the cases at Love Canal, S Area and Hyde Park.

Hyde Park

The Hyde Park landfill site was operated by the Hooker Chemicals and Plastics Company from approximately 1953 until 1975. This site was used to dispose of about 80,000 tons of hazardous chemicals, including calcium fluoride, mercury brine sludge, C-56, organic phosphates, acid chlorides, lindane, trichlorophenol, chlorotoluenes, and chlorobenzenes. This site also contains approximately 2 tonnes of 2,3,7,8-TCDD (23).

There are three main problems with this site. Firstly, the bottom sediments of Bloody Run Creek (flowing from the site to the river) and its tributaries have been contaminated; secondly, the installed leachate and runoff collection systems are inadequate to control the movement of chemicals away from the site; and thirdly, groundwater under and adjacent to the site has been contaminated.

In 1982, agreement was reached between the U.S. EPA and the Occidental Petroleum Company. Under the terms of the agreement, the Occidental Petroleum Company is to investigate the problem and report back to the EPA on possible clean-up procedures in April this year (1984). The clean-up itself is expected to start in 1985.

Although these four sites probably represent the most serious potential hazards to public health, there are many other sites near the river which are not secure and could leak chemicals. These problems will remain for many years. Possibly the greatest hazard from these sites is only now becoming apparent. Evidence suggests that chemical contaminants are entering the bedrock underneath each of the four major sites described above. It is not known if this is occurring at other sites, but it is worrisome because the bedrock is extremely permeable. Contaminants in bedrock will be more rapidly transported to the river than in normal subsurface groundwater flows. It is therefore important to isolate leaking disposal sites from their environment as securely as possible. The New York State Department of Environmental Conservation has adopted a policy of managing wastes in situ. But by pursuing this policy the DEC is committed to extensive perpetual care of these wastes. The possibility of excavation and removal of the contaminated materials has scarcely been mentioned in discussions on remedial activities. Although the short-term financial costs would be considerably higher than those incurred by a perpetual care program, the long-term costs may be significantly less. Also, removal of the wastes would obviously be preferable on environmental grounds. It is therefore recommended that the New York State Department of Environmental Conservation consider the excavation and removal of contaminated materials as an alternative to in situ management at hazardous waste disposal sites of concern.

Clearly, the use of landfilling as a method of hazardous waste disposal has been unsuccessful, because it has resulted in much environmental contamination. In recognition of this New York State recently announced a ban on the landfilling of liquid hazardous wastes, and we would like to commend them for this action. New disposal options are also being considered, such as incineration. We would encourage the development of new alternatives which cause the least disruption to natural resources and ecosystems. It is therefore recommended that the Commissioner of the New York State Department of Environmental Conservation and the Administrator of the U.S. Environmental Protection Agency be requested to consider the development of environmentally sound disposal options as a matter of utmost importance. This should include the development of programs to minimize the quantities of hazardous wastes produced, and to improve their quality whenever possible.

Although individual hazardous waste disposal sites are a problem, evidence suggests that the whole Niagara and Erie County region is contaminated with organic and inorganic chemicals. For example, groundwater below the City of Niagara Falls, New York, contains chemicals in concentrations (in some cases) higher than the influent and effluent water of the Niagara Falls wastewater treatment plant. It has also been shown that the hydrologic gradient in the Niagara Falls area is toward the lower Niagara River, so groundwater is migrating in that direction. If groundwater contaminated by leaking waste disposal sites is widespread, regional groundwater movement will add to the contamination of both the Niagara River and Lake Ontario. It is therefore recommended that the Commissioner of the New York State Department of Environmental Conservation and the Administrator of the U.S. Environmental Protection Agency be requested to investigate the extent and levels of the chemical contamination of groundwater in the Niagara and Erie Country region, and to estimate the likely effects on water quality in the Niagara River and Lake Ontario.

Chemicals in the Niagara River and their Entry into Lake Ontario

Many trace metals have been identified in water samples from the Niagara River. Iron and copper are the only metals which have consistently violated the "objectives" of the 1978 IJC Great Lakes Agreement, although cadmium, chromium and nickel have also exceeded their "objectives". Many organic chemicals have also been identified in water samples, these include PCBs, dieldrin, BHCs, HCB, DDT and its metabolites, endrin, heptachlor/heptachlor epoxide and endosulphan. Pentachlorophenol and TCDD have been identified in the lower Niagara River.

Sediments have also been analyzed. Suspended sediments contain a variety of metals and organics. Although there are no guidelines for chemicals in suspended sediments, concentrations of PCBs exceeded the Ministry of the Environment's dredge spoil guidelines in all samples taken in 1980. Analysis of bottom sediments has shown that many inorganics exceed the MOE guidelines for dredged spoils disposal, and there are detectable concentrations of many organics, including chlorinated benzenes. Biomonitoring studies have confirmed the bioaccumulation of many organic chemicals such as PCBs, BHC and dieldrin in clams. Fish and herring gull eggs have also been shown to accumulate 2,3,7,8-TCDD.

Recently, 2,3,7,8-TCDD has been identified in water samples taken from the lower Niagara River. This is to be expected, because until recently TCDD was leaking from the Love Canal (via the storm sewers) and is probably leaking from the Hyde Park site (via Bloody Run Creek). Until the U.S. discharge permit system is comprehensive and dump sites are prevented from leaking into the river, contaminant loadings from the Niagara River into Lake Ontario can be expected.

An up-to-date compilation of research into the Niagara River is due to be published in May 1984, by the Niagara River Toxics Committee (a coalition of U.S. and Canadian government agencies).

3.2 The Don and Humber Rivers and Mimico Creek

These watersheds are the focus of a five-year study being conducted by the Ministry of the Environment (Toronto Area Watershed Management Strategy Study - TAWMS) (7). The results of the first year's sampling (1981) have been published and are reviewed below.

The study was conducted at twelve river and six sewage treatment plant outfall locations but only two sets of samples were taken, on September 25 and October 1, respectively. The former was intended to represent baseline conditions, and the latter was intended to represent storm conditions. All samples were analyzed for nutrients, metals and physical parameters, but only the storm samples were analyzed for pesticides. The pesticide and PCB concentrations were determined in filtered water samples, but as pesticides and PCBs can be adsorbed to particulate material, concentrations in filtered water can be lower than in unfiltered water. This makes comparison with the Provincial Water Quality Objectives difficult because the objectives are for unfiltered samples. Sediment, clam and fish tissue samples were also collected.

The Ministry of the Environment collected samples from several locations along the watersheds in the study area. Water samples for chemicals from the Don and Humber Rivers were collected only as far south as Pottery Road and Bloor Street, respectively.

Metals

Many of the metal levels measured in water exceeded the Provincial Water Quality Objectives. Copper and zinc most frequently exceeded their objectives; however, cadmium and lead were also in violation on several occasions. Chromium concentrations did not exceed the objective. Data for mercury could not be compared to the objective because the samples used were not filtered, and the objective for mercury is for filtered water samples. Generally, heavy metal concentrations were higher in the Don River than in the Humber River, and the limited data for Mimico Creek (at its mouth only) show that it too, is significantly polluted.

Sediment samples from the Don and Humber Rivers showed that copper, chromium, zinc, cadmium and lead approach or exceed the Ministry of the Environment's dredge spoil guidelines (8). Exceedance was most frequent at the mouth of the Humber River, and in Black Creek (for lead only).

In general, concentrations of metals were much higher for the October 1 samples (storm conditions), although there is only one set of results for sediments in Mimico Creek and the Don and Humber Rivers respectively.

Organic Chemicals

Monitoring programs conducted prior to 1981 and the TAWMS 1981 survey showed that 14 organochlorine compounds (out of 22 tested for) have been detected in river water samples. PCBs were the most commonly found contaminant, and often exceeded their objective. Other compounds frequently detected included BHCs and dieldrin, which were present at concentrations above their respective objectives. Concentrations of heptachlor epoxide and endrin also exceeded the provincial objectives but were detected less frequently.

In addition, diazinon was occasionally detected in both rivers at levels close to the objective; atrazine and simazine (herbicides) were also detected in the Humber River, but only atrazine was detected in the Don River. The herbicides dicamba, 2,4-DP; 2,4-D; 2,3,5,6-T and pentachlorophenol were identified in water samples from the Don River and the Humber River (Humber excluding dicamba). Sediment samples showed detectable concentrations of PCBs, DDT, HCB, chlordane and heptachlor epoxide, particularly at the mouth of the Humber River.

Clams left caged in the study area accumulated PCBs, DDT, chlordane, heptachlor epoxide, and BHCs. Other compounds were HCB, endosulphan and dieldrin. Young-of-the-year fish also accumulated PCBs, DDT, BHC and chlordane, the highest concentrations being found in the Don River and Black Creek.

In general terms, the Don River is slightly more polluted with organochlorine pesticides and PCBs than the Humber River, but organophosphate pesticides were detected at approximately the same frequency in both rivers. Chlorophenoxy and chlorobenzoic acid herbicides (e.g., 2,4-D) were detected more frequently in the Don River water samples. Therefore, the Don River appears to be slightly more polluted with those organic chemicals than the Humber River.

The TAWMS study has started to define the extent of chemical contamination in the Toronto watersheds, and as such, the TAWMS study is to be encouraged. It is therefore recommended that the Minister of the Environment be requested to continue the work toward an abatement strategy for the Toronto watersheds.

3.3 The Metropolitan Toronto Sewage System

3.3.1 Description of Sewage System

There are three types of sewers in Toronto: storm sewers, sanitary sewers, and combined sewers. There are also trunk sewers and three interceptor trunk sewers. Since 1965 the Public Works Department has been conducting a sewer separation program, separating storm sewers from combined sewers. In common with most municipal systems, the sewage system in Toronto was originally designed for the disposal of household sewage. However, industrial wastes are also accepted for treatment.

There are four sewage treatment plants in Toronto, and a fifth which receives some Metro sewage. These are: Main (Ashbridges), Humber, North Toronto and Highland Creek, the fifth is Lakeview. Their capacities are shown below in Table 2.

Table 2

Design Capacities (dry weather flow) of the Metro Toronto Sewage Treatment Plants

	in MGD
Main	200
Humber	90
North Toronto	9
Highland Creek	48
	347

MGD: Million Gallons Per Day

Actual flow rates can be higher than design capacities. This is because the plants were designed to retain and treat sewage for longer than is necessary, so in wet weather treatment time can be reduced. This increases the capacity of the plants to approximately double the dry weather capacity. If the flow is greater than the wet weather capacity, for more than about 2 hours, it receives primary treatment only, is chlorinated and discharged to the lake. According to Metro Works Department, this happens on an average of 2 or 3 times a year.

The sewage treatment process consists of primary and secondary treatments. Primary treatment removes about 40-50% of the suspended solids, as well as some oils and grease. In secondary treatment the flow of sewage is aerated and digested with micro-organisms in the "activated sludge process". A proportion of the sludge is continually fed back into the tanks to "seed" the process. On leaving the aeration tanks a soluble iron salt is added to the sludge to precipitate out phosphate salts. This step is intended to reduce phosphorus inputs to Lake Ontario as high concentrations cause eutrophication (accelerated aquatic plant growth), which damages lake ecosystems. Finally, the effluent is chlorinated in the spring and summer months. Disinfection of effluent is required by the Ministry of the Environment for the protection of recreational water quality and chlorination is the preferred method; a uniform level of chlorination (0.5 mg/L) is specified for all treatment plants. Although this ensures a high bacterial kill, the effect of chlorination on the lake ecosystem (through trihalomethane formation) should be considered. Where treatment plants are efficiently run and the effluent is monitored frequently, it may be possible to reduce this level without impairing kill efficiency. To reduce chlorine inputs to the lake, chlorination levels for each individual treatment plant could be set, rather than have a uniform level for all plants.

The liquid final effluent contains approximately 15 ppm (parts per million) suspended solids, 15 ppm BOD (biochemical oxygen demand), 50 mg/L dissolved solids, 1 mg/L or less of phosphorus (1 mg/L is the maximum allowable level) and heavy metals. Liquid effluent is sampled and analyzed hourly, the results being averaged daily.

Liquid effluents from the treatment plants (except North Toronto) enter Lake Ontario via outfall pipes. A new outfall pipe is being planned for the Main treatment plant. It is recommended that computer modelling of the dispersion characteristics of the most significant chemicals (e.g., chlorine and heavy metals), identified in the Main treatment plant effluent, be included in the planning process.

At the conclusion of the treatment process, the removed solids are digested anerobically by micro-organisms and the digested sludge is de-watered by vacuum filtration. Sludge is incinerated at the Main treatment plant and in mid-1984, it will also incinerate sludge from the Humber treatment plant.

3.3.2 Municipal Sewage By-Law

Discharges into the sewage system are regulated by Metropolitan Toronto By-law No. 148-83. It establishes maximum permissible concentrations (see Table 3) for discharges into a sanitary or combined sewer (see column A in Table 3) and into a storm sewer, drain or land drainage works capable of discharging into a body of water or onto a shore or bank (see column B).

Table 3

Maximum Permissible Concentrations of Chemicals Discharged to the Toronto Sewage System

	A (in mg/L)	B (in mg/L)
Aluminium	50	1.0
Ammonia	-	10.0
Arsenic	1.0	1.0
Barium	5.0	1.0
Cadmium	2.0	0.1
Chlorine/Chloride	1500	1.0
Chromium	5.0	1.0
Copper	5.0	1.0
Cyanide	2.0	0.1
Fluoride	10.0	2.0
Iron	50.0	1.0
Lead	5.0	1.0
Manganese	-	1.0
Mercury	0.1	0.001
Nickel	5.0	1.0
Phenolic compounds	1.0	0.02
Phosphorus	100	1.0
Sulphate	1500	-
Sulphide	2.0	-
Tin	5.0	1.0
Zinc	5.0	1.0

A: Maximum permissible concentrations for sanitary or combined sewers

B: Maximum permissible concentrations for storm sewers, storm sewer connections, storm drains, watercourses, or land drainage works.

The By-law imposes a maximum fine of $2,000 for each offence in each single day as long as the offence continues. It is enforced by only 14 municipal inspectors who sample industrial sewers (storm and sanitary) periodically.

Under the By-law, industrial waste "which exceeds the maximum permissible limits but is amenable to treatment at Metropolitan treatment plants" may be admitted into sanitary sewers by special agreement, whereby a surcharge is levied "to compensate for the cost of treating the excessive waste concentrations". There were approximately 85 special arrangements made in 1982 (about 1 in 25 of the wet processing industries in Metro Toronto).

This By-law is designed to protect the treatment facilities (in particular the micro-organisms) and personnel, rather than to minimize the input of pollutants to the lake. While the above-mentioned objectives are necessary, attention should also be given to the impact of contaminant loadings on the lake ecosystem.

3.3.3 Sewage Effluent Quality

Storm Sewers

Storm sewers can discharge into receiving waters and there are approximately 16 which empty directly into the central waterfront area. Although industrial effluents should only be discharged into sanitary or combined sewers, illegal connections to storm sewers have been found. The Metro Works Department does not monitor storm sewers routinely but they do analyze samples from receiving waters (the Humber and Don Rivers, Mimico, Highland and Etobicoke Creeks). Samples are analyzed for temperature, dissolved oxygen, BOD (biochemical oxygen demand), coliform count, turbidity, and suspended solids (if necessary). These parameters do not provide a direct measurement of chemical contamination, although they are adequate to assess biological contamination. It is probably difficult to quantify contaminant concentrations in receiving waters because they will be more diluted than the sewer itself. In addition to the river and creek sampling conducted by the Metro Works Department, the Public Works Department conducts similar sampling for nearshore Lake Ontario for the total coliform count only. Beach sampling is conducted by the Department of Public Health.

Recently, storm sewer outfalls and combined sewer overflows into the central waterfront region were sampled, and the samples chemically analyzed as part of the Toronto Area Watershed Management Strategy Survey. The results of this analysis are expected to be released later this year. This program is to be commended, and it is recommended that a comprehensive analysis of all storm sewer outfalls and combined sewer overflows be conducted at least once a year, using the U.S. Environmental Protection Agency's list of "priority pollutant" chemicals as a basis.

Combined Sewer Overflows

Combined sewers, including trunk and interceptor sewers, have overflows, so it is possible for household and industrial effluents to enter receiving waters untreated. There are approximately 25 such overflows in the central waterfront. The Public Works Department estimates that such overflows occur approximately 5% of the time in any given year, depending on weather conditions, but they are unable to estimate the volumes. Most occur at the interceptor level and enter the lake but, as mentioned above, the only analysis is a count of total coliforms. Thus, the quantity and quality of untreated chemical effluents entering the lake is unknown. As mentioned above, samples from the combined sewer overflows and the storm sewer outfalls into the central waterfront have recently been analyzed, and it is recommended that a comprehensive analysis be undertaken at least once a year using the U.S. Environmental Protection Agency's list of "priority pollutant" chemicals as a basis.

Sewage Treatment Plant Effluents

The sewage treatment plants were not designed to treat chemical effluents, but they probably do not pass through the process unaltered. In order to understand what changes occur, it would be necessary to analyze the chemical quality of incoming sewage and outgoing wastewater and sludges. The Metro Works Department does analyze samples of incoming material and outgoing wastewater and sludges for: BOD (biochemical oxygen demand), suspended solids, phosphorus and pH, and additionally outgoing materials for a total coliform count and heavy metals (arsenic, mercury, cadmium, chromium, copper, lead, nickel, and zinc).

Recently, the Metro Works Department completed a chemical analysis (based on the U.S. EPA's list of "priority pollutant" chemicals) of the effluents from all four of the sewage treatment plants. The results of this analysis are due to be presented to the Metro Works Committee in April, 1984. This program is to be commended, and it is recommended that such an analysis be conducted at least once a year. It is also recommended that the chemical analyses of samples from the storm sewer outfalls, the combined sewer overflows and the sewage treatment plants' effluent be integrated by using the same list of chemicals, and standardized sample collection and analytical procedures.

Some organic chemicals in the effluent may be used as nutrients by micro-organisms in the treatment process, but because of the diversity of metabolic pathways, it is impossible to predict what new compounds may be formed. It is also difficult to predict the fate of heavy metals; some may be utilized in metabolic processes, while others may not. The fate of both will largely depend on their form (attached to suspended solids or in solution). If they are in solution or attached to very fine particles, they are more likely to be oxidized by aerobic micro-organisms, while if they are adsorbed to suspended solids they are likely to be reduced and appear in the sewage sludge. Heavy metals which are analyzed for are generally below the maximum permissible concentrations.

The concentrations of heavy metals in treatment plant effluents generally exceed their respective Provincial Water Quality Objectives, but this is to be expected from point sources such as sewage treatment plant outfalls. In cases where point sources do not meet the relevant objectives, the Ministry of the Environment requires that "zones of non-compliance" be designated on a case-by-case basis, taking account of existing biological, chemical, physical and hydrological conditions. These zones define areas of excessive pollution. It is recommended that where required, "zones of non-compliance" should be designated for point sources of contaminants along the Toronto waterfront.

3.4 Lakefilling at the Leslie Street Spit and Dredging Operations in the Inner Harbour and Keating Channel

The effects of dredging and lakefilling on the Toronto nearshore zone have been studied by the Ministry of the Environment (17,18,19).

These studies are intended to assess only the short-term effects of dredging and dredgeate disposal on water quality as related to the protection of aquatic life and its use for recreational purposes. But some analysis of raw and finished drinking water samples has also been done.

The Ministry's data are based on a network of sampling stations located in the Inner Harbour, the Outer Harbour, the area adjacent to the Outer Harbour, the water intakes and the sewage treatment plant outfalls. The numbers and locations of these stations have varied over the two years of data reported, so an evaluation of pollution over time is difficult. The depth of sampling is also important. Since 1980, neither organic nor inorganic chemicals have been comprehensively analyzed in samples taken at increasing depths; all samples were taken at 1.5m. Many chemicals are adsorbed to particulate matter which settles out in the lake, so that chemical concentrations may increase with increasing depth.

To examine the effects of dredging and lakefilling on water quality, samples have been analyzed for several metals, some organochlorine pesticides and PCBs, although in 1980 most of the analyses were for metals only. Concentrations were slightly higher near dredging and lakefilling sites. Bearing in mind that much of the land used as lakefill originated at industrialized sites, it would also seem appropriate to analyze samples for commonly found industrial organic chemicals such as solvents.

It is not surprising that concentrations are slightly higher near the lakefilling site. The Lakefill Quality Study, 1982, conducted by Environment Canada and the Ministry of the Environment, at the Leslie Street Spit, found that 51% of trucks sampled (carrying fill to be deposited at the Spit) exceeded one or more of the Ministry of the Environment's Lakefill Quality Guidelines, which cover 12 metals and six other substances. The metals which most frequently exceeded the guidelines were, in order of decreasing frequency, chromium, copper, lead, mercury and arsenic.

When fill is dumped, the smaller particles become suspended in a "plume" extending into the lake. Under "moderate" wind conditions such plumes have been observed extending from the lakefilling site approximately 1.5 km. It is likely that under severe wind conditions they would extend considerably further. Plumes have not been specifically chemically analyzed, and mapping of their directions and sizes under different metereological conditions should to be done. However, some sampling stations are located in areas from which one could expect plumes to originate, or to encompass.

The distance from the lakefilling site to the R.C. Harris water intake pipes is approximately 6 km, and to the Island filtration plant intakes approximately 5 km. These distances are approximately 3 times the lengths of plumes observed under moderate wind conditions. The predominant currents along the Toronto waterfront are to the west but currents to the north and the east also occur. Therefore, the potential effects to both intakes should be considered.

Some metals may be transported beyond the plume because of their solubility. Routine analyses of raw water at the intakes for the R.C. Harris and Island filtration plants show that heavy metal concentrations are comparable with those at the Easterly and R.L. Clark plants (i.e., ambient lake concentrations). Thus, there is no evidence that dredging, dredgeate disposal or lakefilling contribute contaminants to Toronto's drinking water, although the potential does exist.

In 1983 the Ministry released an environmental assessment on the dredging of the Keating Channel and disposal of the dredgeate. Normally, the proponent of such an undertaking is required to have completed the assessment process before it can be initiated.

However, the Keating Channel was dredged, with Ministry approval, in both 1980 and 1981.

The Keating Channel environmental assessment has recently been reviewed by the Departments of Public Health, Planning and Development, and Public Works. The review concludes that, while dredging appears to be necessary, the methods for dredgeate disposal could be improved. The Minister of the Environment is expected to announce whether there will be public hearings on this environmental assessment in the near future.

3.5 Relative Source Loadings to the Toronto Waterfront

It is extremely difficult to estimate the relative sizes of the loadings of chemical contaminants along the Toronto waterfront. This is partly because estimates of contaminant loadings at the mouths of the Don and Humber Rivers have not been made, and partly because there are so many sources. These include the combined sewer overflows, and the storm sewers. The relative contributions of lakefilling, dredgeate disposal and dredging have not been quantified either.

The simplified estimates of source loadings that follow are for four point sources only: the Main sewage treatment plant, Mimico Creek, the Don River, and the Humber River. Estimates of flow rates were obtained from Environment Canada, the Metro Works Department, and the Metro Toronto and Region Conservation Authority. Contaminant concentrations were obtained from the TAWMS study and the Metro Works Department. These were then converted to daily loading weights using the flow rate estimates. Figures for the Don and Humber Rivers are taken from the Pottery Road and Bloor Street sample collection station (i.e., the furthest south) and may not represent loadings to the lake. Also, sampling of the four point sources was not conducted on the same day, and in any case, information from a single set of samples may not be representative of average concentrations. For example, pesticide concentration in rivers will vary seasonally.

Table 4

Relative Source Loadings to the Toronto Waterfront

kilograms per day

Metal	MTP	Mimico Creek	Don River	Humber River
Cadmium	1.8	-	-	-
Chromium	6.3	1.6	6.6	5.2
Copper	27	0.7	10.8	4.3
Lead	24	-	1.8	-
Zinc	90	0.8	8.4	4.3

grams per day

	Mimico	Don	Humber
PCB	1.2	-	7.6
HCB	0.2	-	0.4
BHC isomers	-	24.6	4.5
Chlordane isomers	-	7.8	1.3
Endosulphan	-	0.6	2.6
Heptachlor epoxide	-	1.2	1.3
Dieldrin	-	2.1	2.2

MTP = Main sewage treatment plant

It was only possible to obtain complete data for three metals: chromium, copper and zinc. Table 4 shows that the Main sewage treatment plant effluent contains approximately 30% of the total chromium, 60% of the total copper and 90% of the total zinc.

For pesticides, the Don and Humber Rivers contribute approximately equal amounts to the lake, but for PCBs the Humber is the main contributor.

Although these figures are very approximate, they do provide an indication of relative source loadings. It is recommended that the Ministry of the Environment estimate relative chemical contributions from all sources along the Toronto waterfront. This would enable contaminant reduction programs to be more effectively planned than at present.

3.6 Other Sources

Urban Runoff

Urban runoff results mainly from rain washing over paved, asphalted or built-up areas which eventually enters Lake Ontario. There are two types of urban runoff; those containing heavy metals and possibly other chemicals, and those that also contain de-icing salts (chloride). Little is known about the content of urban runoff. One would expect to find metals and other compounds that are normally associated with gas and diesel exhaust fumes, in particular, lead.

In 1978 the Ministry of the Environment published a report which assessed the significance of chloride inputs (from de-icing salts) to Lake Ontario (10). Although de-icing salts represent the major chloride input in the Toronto area, the input from the Niagara River is much larger (annual loadings are approximately 219,370 and 4,620,000 tonnes, respectively). The Ministry concluded that despite large fluctuations and high winter chloride concentrations in the Toronto watersheds, there is no evidence to suggest that the use of de-icing salt is significantly affecting Lake Ontario.

Street washing results in large volumes of relatively unpolluted runoff entering the storm sewers. Runoff from rain water alone would be much more polluted. So even though the total loadings would be equivalent, the impact on the lake ecosystem is probably lessened by the diluting effect of street washing. In addition, some street washing trucks can collect the used water.

Rural Runoff

Rural runoff results from rain percolating through soil and draining to streams, rivers and eventually to the lake. Its composition is different from urban runoff, but is also highly variable. Studies of rural runoff have focussed on pesticides. The IJC has commented that there are insufficient data to allow an assessment of the contribution of organic chemicals and metals from agricultural, silvicultural and other land use activities, to rural runoff (11). This was also the conclusion reached by the Pollution from Land Use Activities Reference Group (PLUARG) of the IJC, which was established in 1972 to examine the effects of land use on Great Lakes pollution. Their final report stressed that "effective strategies at the international, national and local levels must be developed to cope with pollution from land use activities" (12). The TAWMS study (reviewed above) is an attempt to fulfill this need.

Pesticides in agricultural runoff have been reviewed by Willis and McDowell (13). Aerial losses (by volatilization) are probably greater than runoff losses, and contribute greater quantities of pesticides to the aquatic environment. The magnitude and frequency of losses are only now being characterized (for example, see reference 14). Factors affecting the concentration of pesticides in runoff include: rain characteristics, the time interval between pesticide application and rainfall, the persistence of individual pesticides, the rate of application, the mode of application, soil texture and topography, antecedent moisture, the type and amount of ground cover, and the distance of transport. The first three factors are the most important.

Several pesticides have been identified in water samples from Lake Ontario which could have entered the lake via runoff. These include DDT and some of its metabolites, and some BHC derivatives.

Atmospheric Sources

Until recently the impact of atmospheric deposition on water quality has been neglected. To compensate for this the U.S. EPA funded two reports on organic and inorganic contaminants, respectively, in the Great Lakes ecosystem. There is also an IJC task force investigating this problem. (15,16).

Estimates of atmospheric deposition are somewhat vague because of uncertainties about atmospheric concentrations, metereological conditions, and other factors. For organic contaminants, dry deposition is significantly greater than wet deposition. The data also suggest that total deposition of organic chemicals to each of the Great Lakes is proportional to their surface area. Estimates of annual deposition of organic and inorganic chemicals to Lake Ontario are shown in Table 5 (21).

Table 5

Annual Deposition of Organic and Inorganic Chemicals to Lake Ontario

	metric tonnes/year
Total PCBs	2.3
Total DDT	0.14
alpha-BHC	0.77
gamma-BHC	3.7
Dieldrin	0.13
HCB	0.39
Methoxychlor	1.9
Endosulphans	3.7
Zinc	948
Lead	379
Copper	95
Cadmium	28
Nickel	76
Iron	1,520
Total PAHs	38
Anthracene	1.1
Phenanthrene	1.1
Pyrene	1.9
Benzo (a) anthracene	1.1
Perylene	1.1
Benzo (a) pyrene	1.8
DBP	3.7
DEHP	3.7
Total Organic Carbon	4.6×10^4

The figures show that large amounts of organic and inorganic chemicals are deposited every year. The sum of the weights of organic chemicals deposited is much less than the estimated weight of total organic carbon deposited into the lake. This suggests that some sources of organic carbon remain to be identified and measured. For example, it is likely that dioxins (from incinerators and other sources) are being atmospherically deposited into the lake.

Atmospheric deposition is probably a major source of pollutants to Lake Ontario, and research into the amount of deposition, its nature, origin, and how it might be prevented has only just started. It is therefore recommended that the IJC be encouraged to investigate atmospheric deposition to the fullest extent possible.

3.7 Recommendations

Niagara River:

1. That the Commissioner of the New York State Department of Environmental Conservation be requested to review the basis for the SPDES (State Pollutant Discharge Elimination System) permits. Such a review should examine whether it is appropriate to include considerations of ambient contaminant concentrations in the Niagara River, chemical contaminants entering the river from non-point sources, and the water quality objectives of the Great Lakes Agreement, 1978, in discharge permits.

2. That the Commissioner of the New York State Department of Environmental Conservation be requested to encourage the regulation of more of the U.S. Environmental Protection Agency's priority pollutants in all new and renewed SPDES permits.

3. That the Director of Utilities for the City of Niagara Falls, New York be requested to complete the necessary remedial work on its wastewater treatment plant as soon as possible.

4. That the Commissioner of the New York State Department of Environmental Conservation and the Administrator of the U.S. Environmental Protection Agency be requested to consider the excavation and removal of contaminated materials as an alternative to in situ management of the leaking waste disposal sites most likely to contribute to the contamination of the Niagara River.

5. That the Commissioner of the New York State Department of Environmental Conservation and the Administrator of the U.S. Environmental Protection Agency be requested to consider the development of environmentally sound disposal options as a matter of utmost importance. This should include the development of programs to minimize the quantities of hazardous wastes produced, and to improve their quality wherever possible.

6. That the Commissioner of the New York State Department of Environmental Conservation and the Administrator of the U.S. Environmental Protection Agency be requested to investigate the extent and levels of the chemical contamination of groundwater in the Niagara and Erie County region, and to estimate the likely effects on water quality in the Niagara River and Lake Ontario.

Don and Humber Rivers and Mimico Creek:

7. That the Minister of the Environment for Ontario be requested to continue to work toward abatement strategies for the Toronto watersheds.

Metro Toronto Sewage System:

8. That the Commissioner of the Works Department, Metropolitan Toronto be requested to include computer modelling of the dispersion characteristics of the most significant chemicals (e.g., chlorine and heavy metals) identified in the Main treatment plant effluent, in the planning process for the new outfall pipe.

9. That the Commissioner of the Public Works Department, City of Toronto, be requested to undertake a comprehensive chemical analysis of all storm sewer outfalls and combined sewer overflows at least once a year, using the U.S. Environmental Protection Agency's list of "priority pollutant" chemicals as a basis.

10. That the Commissioner of the Works Department, Metropolitan Toronto, be requested to chemically analyze effluent samples from all four Metro Toronto sewage treatment plants at least once a year using the U.S. Environmental Protection Agency's list of "priority pollutant" chemicals as a basis.

11. That the Commissioner of Works, Metropolitan Toronto and the Commissioner of Public Works, City of Toronto, be requested to integrate the programs of chemical analysis mentioned in recommendations (9) and (10) above, by using the same list of chemicals, and standardized sample collection and analytical procedures.

12. That the Minister of the Environment for Ontario be requested to define or have defined, and make public, "zones of non-compliance" with the Provincial Water Quality Objectives for point sources of contaminants to the Toronto waterfront.

Relative source loadings:

13. That the Minister of the Environment for Ontario be requested to develop a consistent year round monitoring program for the Toronto waterfront, to be based on an assessment of the relative contributions of all point sources of chemical contaminants.

Non-point Sources:

14. That the Chairmen of the Great Lakes Science Advisory Board and the Water Quality Board of the International Joint Commission be requested to investigate the atmospheric deposition of organic and inorganic chemicals into Lake Ontario to the fullest extent possible.

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4. METROPOLITAN TORONTO WATER FILTRATION PLANTS

4.1 Background Information

There are four filtration plants in Toronto operated by the Metro Works Department. These are the R.C. Harris, R.L. Clark, Island and Easterly filtration plants, of which R.C. Harris is the largest. The four plants have a combined capacity of 524 MGD (see Table 6).

Table 6

Capacities of Metro Toronto's Water Filtration Plants

	MGD
R.C. Harris	220
R.L. Clark	100
Easterly	100
Island	104

MGD = million gallons per day.

Details of the filtration and disinfection methods used at the different plants vary slightly, but the same general principles are used, and all four plants use Lake Ontario as their source of raw water. The water quality at the intakes may vary because of their locations relative to sources of pollution along the Toronto waterfront.

The water intakes are situated in 14-18m of water at distances varying from 760m (Island) to 2960m (Easterly) from the shore. In the first filtration step the intake water is screened to remove large particles of suspended debris. It is pre-chlorinated to control biological growth in the plant. Chlorine is usually added to 1.5-3.0 mg/L, resulting in a residual of 0.3-0.5 mg/L. A study of pre-chlorination was conducted by the Ministry of the Environment in 1979 (1).

The next step is to "coagulate" the water using ferric chloride, which forms "floc" (a jelly-like substance), combining with suspended impurities. Until mid-February this year (1984) coagulation was intermittently performed. Now it is a continuous process. The water passes through settling basins and is filtered to remove the "floc". Rapid sand filters are used in which the water flows downward through a layer of sand on top of a layer of gravel, supported by an underdrain. The sand layer can be replaced by layers of sand and anthracite. The material that accumulates in the filter is periodically removed by "backwashing" which involves passing water upward through the filter. Water used for backwashing is released to the lake.

The final steps in the filtration process disinfect the water. Chlorine is added to destroy micro-organisms such as bacteria and algae. It also controls undesirable tastes and odours, but this requires higher doses and is called superchlorination. Unfortunately, chlorine itself has a taste and odour objectionable to some people. The chlorine residual in the water is reduced to approximately 0.5-0.6 mg/L by reaction with sulphur dioxide. The water is also fluoridated using hydrofluosalicic acid, to a concentration of approximately 1 mg/L as a preventive dental health measure. Finally, the water is ammoniated; ammonia is added which combines with the residual chlorine to produce chloramines, which are more persistent than free chlorine and disinfect the water throughout the distribution system.

Following water filtration the finished water is pumped into the distribution system, to storage and eventually to the consumer. The effects of the distribution system on drinking water quality will be discussed in Section 5.

Products of Chlorination

When chlorine is added to disinfect drinking water, many chemical reactions occur. The best known results in the formation of chloroform and other trihalomethanes (dibromochloromethane, bromodichloromethane and bromoform).

It is likely that naturally occurring humic and fulvic acids react with chlorine. These substances are breakdown products from living and decaying plants and/or soil runoff. They are very diverse chemically and, consequently, their chemical reactions are also diverse. It is likely that in aqueous environments chlorine reacts with humic acids to produce trihalomethanes, which are animal carcinogens. Chloroform, at least, is also a human carcinogen. Non-halogenated products may also result (such as benzene rings or cyclic hydrocarbons), although the adverse Health effects of such substances are largely unknown.

A variety of factors influence the final concentrations of trihalomethanes. These include the respective amounts of precursor materials and free available chlorine, the length of contact, the water pH, the stage in the water treatment process at which chlorine is added, filtration and sedimentation practices, and the presence of other substances such as ammonia. A major U.S. study, Drinking Water and Health, suggests that it is important to understand the mechanisms underlying trihalomethane formation so as to avoid conditions that promote high trihalomethane concentrations in finished water (2).

In addition to the reaction between chlorine and humic acids, other substances present in raw water may also react. Phenols have been shown to react forming chlorophenols, and polyaromatic hydrocarbons react to form a variety of chemicals, some of which are potential or suspect carcinogens. Although current attention on the carcinogenicity of trihalomethanes may be valid, the possible adverse health effects of all the chemical products of chlorination should be investigated and put in perspective relative to the advantages of chlorine as a disinfectant.

It is now well-established that chlorination increases the mutagenicity (in the Ames test) of drinking water (13), and Cheh et al concluded that chlorination was responsible for non-volatile as well as volatile mutagen production (14). Trihalomethanes comprise the major portion of volatile compounds in treated drinking water. But they only cause a fraction of the mutagenic activity (15). This suggests that much of the activity is due to non-volatile compounds. Evidence shows that not only are most mutagens carcinogenic (16), but also that there is a correlation between the potency of mutagens and their carcinogenic ability (17). Therefore this large unidentified portion of mutagenic activity, consisting of non-volatile compounds, should be regarded as potentially carcinogenic. It is recommended that Health and Welfare Canada investigate the health effects of the non-volatile mutagenic fraction of chlorinated drinking water in animals to determine its carcinogenic potential.

As mentioned above, chlorination increases the mutagenicity of drinking water (13). One study of Great Lakes water showed that chlorinated water was more mutagenic than raw lake water by factors of between 2 - 10 times (18). This suggests that chlorination is the largest single source of potentially hazardous chemicals to drinking water. However, in making this statement we acknowledge the tremendous public health benefits that have resulted from the use of chlorine, the main one being the virtual eradication of waterborne communicable diseases such as typhoid, cholera, dysentery and infectious hepatitis.

In view of the fact that chlorination is probably the largest source of potentially hazardous chemicals, we recommend that Health and Welfare Canada be requested to consider initiating a research program to investigate possible alternatives to the use of chlorine as a drinking water disinfectant. Alternative disinfectants are discussed in Section 9.

4.2 Chemicals Identified in Toronto's Raw and Finished Drinking Water

Inorganic and organic analyses of raw and finished drinking water are performed approximately twice a year, although some inorganic analyses are conducted monthly. The table in Appendix 1 shows eighty-three inorganic and organic chemicals that have been identified in Toronto's drinking water. The concentrations shown represent the highest found for each chemical. They do not represent chemical concentrations from samples taken at the same time. This number compares with fifty-three identified by Pollution Probe in Drinking Water: Make It Safe! (4). Of these, twenty-eight are inorganics, and fifty-five are organics, although inorganics have been detected more frequently. Seven of the eighty-three are human carcinogens, and approximately twenty-three (excluding polyaromatic hydrocarbons, some of which are animal carcinogens) are potential carcinogens. The potential health effects resulting from exposure to these chemicals are discussed in Section 8.

The number of chemicals detected in Toronto's drinking water has been increasing in recent years. This is probably partly because analytical detection levels are becoming more sensitive, and more chemicals are being analyzed for, and partly because chemical contamination is worsening.

Analyses for drinking water are performed by comparing a sample with standard samples of the chemicals for which the water is being analyzed. Thus, only specific chemicals can be identified. In a more time-consuming procedure it is possible to identify chemicals for which no standard samples have been included. It is recommended that this procedure be used on at least one set of samples in 1984 by the Metro Works Department. When this was done for a sample of tap water analyzed by the Department of Public Health, three additional organic chemicals were identified.

The maximum concentrations of chemicals identified in Toronto's drinking water are compared with the Canadian drinking water guidelines in Section 7.4.

4.3 The Effectiveness of the Existing System in Removing Organic and Inorganic Chemicals

The existing water filtration and disinfection procedure was not designed to remove chemical contaminants from drinking water, although it undoubtedly affects both organic and inorganic chemicals present. The U.S. study, Drinking Water and Health (2), discusses the removal of organics by coagulation, sedimentation and filtration. It concludes that some organics adsorb either on natural particles or on those formed during coagulation, and that they are removed when the particles are filtered out. This hypothesis is supported by evidence showing total organic carbon (TOC) removals of between 25 and 60%. Humic acids have been shown to be removed most efficiently at acid pH. Lake Ontario water is slightly alkali, so removal may not be good. Data on dissolved organic carbon in Toronto's raw and finished water (3), show that there is only a 5-10% decrease after treatment.

Removal of specific organics, such as polyaromatic hydrocarbons and some organochlorine pesticides, has been demonstrated to occur in the coagulation process (2), but data on Toronto's filtration plants are equivocal. When concentrations of specific synthetic organics before and after the treatment process are compared, it can be seen that the process has little effect. But because synthetic organics (other than trihalomethanes) are only infrequently detected in Toronto's drinking water, this conclusion is based on few data.

Evidence of the removal of inorganics is also equivocal. Most inorganics in Toronto's drinking water are present at concentrations at which they may be soluble, although this will depend on such factors as pH and temperature. Concentrations of inorganics before and after treatment show no consistent patterns, either for inorganics generally or for specific ones. In some instances concentrations increase after filtration, in some they stay the same, and in others they decrease. There is also variability in the behaviour of individual chemicals. Possible reasons for this include the presence of trace elements in the chemicals used in the filtration and disinfection processes. The only conclusion that can be drawn is that the existing water filtration and disinfection processes affect concentrations of inorganics unpredictably.

4.4 Comparison of Toronto's Drinking Water Quality With Other Drinking Water Supplies

4.4.1 Comparison with U.S. Drinking Water Quality

Several national studies have been conducted on the quality of U.S. drinking water. Perhaps the best known of these are the National Organics Monitoring Survey (5), and the National Organics Reconnaissance Survey (6). More recent studies have included the 1978 Community Water Supply Survey, the National Organics Screening Program, the Groundwater Supply Survey and the Rural Water Supply Survey.

Table 7 shows a comparison between the maximum concentrations of some inorganics in Toronto's finished water (1971-83) and the maximum concentrations from one sampling of 380 finished water supplies in the U.S.

Table 7

Comparison Between the Maximum Concentrations of Inorganics in Toronto and the U.S.

Element	U.S. max. conc. (ug/L)[1]	Toronto max. conc. (ug/L)[2]
Barium	172	520
Cadmium	12	10
Chromium	29	6
Copper	1060	145
Lead	139	10
Nickel	490	11
Silver	5	67
Zinc	2010	64

[1] based on data in Drinking Water and Health Vol 1. p. 211.

[2] For 1971-82, as supplied by the Metro Works Department.

The data show that the maximum concentrations of inorganics in the U.S. are generally higher than Toronto's. A more accurate comparison would be to compare a number of samples from Toronto with an equivalent number from several U.S. locations.

Organics

The U.S. data used for the comparison of organics has been taken from The Occurrence of Volatile Organics in Drinking Water (8), and An Overview of Organics Data; Community Water Supply Survey and Rural Water Survey (9).

Maximum trihalomethane concentrations are compared in Table 8. U.S. concentrations are taken from 105 samples of finished water from surface sources, and Toronto concentrations are taken from data supplied by the Metro Works Department.

Table 8

Comparison Between the Maximum Concentrations of Organics in Toronto and the U.S.

Compound	U.S. max. conc. 1978 (ug/L)	Toronto max. conc. 1978-83 (ug/L)
Chloroform	700	41.3
Bromodichloromethane	62	42
Dibromochloromethane	45	6.3
Bromoform	5.7	3
Total Trihalomethanes	700	18

This comparison suggests that U.S. drinking water contains substantially higher concentrations of trihalomethanes than Toronto's drinking water. It is not clear why the highest concentration of total trihalomethanes is 18 ug/L, but the highest concentration of two trihalomethanes (chloroform and bromodichloromethane) are themselves substantially higher than this figure. U.S. concentrations are based on 1978 data. It is likely that concentrations have decreased in recent years because of the implementation of the 100 ug/L maximum contaminant level for trihalomethanes. As for inorganics, a more accurate comparison would be to compare a number of samples from Toronto with an equivalent number from several U.S. locations.

It is difficult to compare other classes of organics using a tabular form because there are few organics that have been identified on a consistent basis in both U.S. and Toronto drinking water. Many more organics have been identified in U.S. drinking water and there is a higher frequency of detection.

4.4.2 Comparison With Other Municipal Drinking Water Supplies in Canada

There have been several studies of Canadian drinking water. These include one by Health and Welfare Canada which compared the mutagenicity and organic chemical content in drinking water of 14 Ontario municipalities (10), another which compared trihalomethane concentrations across Canada (11), and a third by the Ontario Ministry of the Environment which surveyed organic concentrations in municipal water supplies (12).

The Health and Welfare study examined finished drinking water from the following municipalities: Thunder Bay, Sault Ste. Marie, Owen

Sound, Goderich, Sarnia, Amherstburg, Union-Leamington, Port Dover, Port Colborne, St. Catharines, Toronto and Kingston. The results showed that mutagenicity increased from the northwest as far as Port Dover and then decreased east to Kingston. The mutagenic potential of Toronto's drinking water ranked ninth out of eleven, where one was the least mutagenic and eleven the most mutagenic (see Appendix 4). Therefore Toronto's water was one of the more mutagenic samples tested.

This study also analyzed drinking water samples for four classes of organic chemicals: polyaromatic hydrocarbons, organochlorine pesticides, trialkyl/aryl phosphates and trihalomethanes. Table 9 compares the concentrations at each of the municipalities. .

Table 9

Concentrations of Organics in 12 Ontario Municipalities

(Summer)	Total PAH ng/L	OC ng/L	TAAP ng/L	THM ug/L
Thunder Bay	33.7	10.6	4.1	15.4
Sault Ste. Marie	3055.1	11.5	1.5	1.5
Owen Sound	111.6	7.1	4.2	17.8
Goderich	50.6	0.5	3.5	15.0
Sarnia	8.3	7.8	4.5	15.9
Amherstberg	13.7	6.7	3.9	19.1
Union-Leamington	181.6	3.8	7.6	11
Port Dover	52	5.3	10.6	16.2
Port Colborne	53.3	2.7	13.1	13.1
St. Catharines	27.1	3.4	31.0	12.0
Toronto	15.9	5.3	55.9	26.9
Kingston	57.6	1.6	31.7	18.2

PAH = polyaromatic hydrocarbons

OC = organochlorine pesticides

TAAP = trialkyl/aryl phosphates

THM = trihalomathanes

The results show that Toronto's water contains more trialkyl/aryl phosphates and more trihalomethanes than other municipalities in the study. However, the samples are not averaged, so the concentrations shown may not be representative. In general, Toronto's drinking water is slightly more contaminated with the organics tested for than the other Ontario municipalities.

It is interesting to note that there was no correlation between mutagenic potential and the presence of the analysed organics.

In 1977 Health and Welfare Canada conducted a survey of trihalomethane concentrations in the drinking water of 70 Canadian municipalities. The results are compared with Toronto's trihalomethane concentrations in Table 10.

Table 10

Trihalomethane Concentrations in the Drinking Water of 70 Canadian Municipalities

	Canadian (1977) Range (ug/L)	Toronto (1971-82) Range (ug/L)
Chloroform	0 - 121	1.9 - 41.3
Bromodichloromethane	0 - 33	2.3 - 42
Chlorodibromomethane	0 - 6.2	1.6 - 6.3
Bromoform	0 - 0.2	3

These results show that chloroform concentrations are lower in Toronto's water than at many other Canadian locations (also see the MOE study reviewed below). But, bromodichloromethane, chlorodibromomethane and bromoform concentrations are all higher in Toronto's drinking water than in other Canadian municipalities. Toronto was one of the municipalities in the national survey, but the differences between the Canadian range and the Toronto range are probably because the Toronto concentrations cover a longer period of time (1971-82), whereas the national survey was conducted in a single year (1977).

The study conducted by the MOE determined trihalomethane concentrations at 48 Ontario water treatment plants. Brantford had the highest chloroform concentration (159 ug/L); those at the Toronto plants were much lower (8 ug/L), although higher concentrations have been reported (15-20 ug/L) by the Metro Works Department. These concentrations for Toronto's drinking water are somewhat lower than those reported by Health and Welfare Canada (see Table 9).

The study also found atrazine at 8 locations, the highest concentration being 0.45 ug/L. Toronto's drinking water contained a trace amount. In addition, pesticides (dieldrin and lindane) were identified at three locations (not Toronto), and aromatic hydrocarbons (benzene, toluene, etc.) were detected at seven locations (not Toronto). No PCBs were found.

In summary, Toronto's drinking water compares reasonably with other Ontario and Canadian municipalities for organic contamination. Unfortunately, there were no data available on variations of inorganic concentrations in Canada or Ontario, and most of the organic data is for trihalomethanes. It is therefore recommended that a national survey of organics and inorganics in Canadian drinking water be undertaken by Health and Welfare Canada and/or Environment Canada. This would provide a comprehensive view of Canadian drinking water quality and would facilitate future policy and legislative decisions.

4.5 Recommendations

15. That the Minister of National Health and Welfare be requested to investigate the health effects of the non-volatile mutagenic fraction of chlorinated drinking water in animals to determine its carcinogenic potential.

16. That the Minister of National Health and Welfare be requested to initiate a research program to investigate possible alternatives to the use of chlorine as a drinking water disinfectant. This could also include an evaluation of alternatives to conventional filtration methods, such as granular activated carbon.

Analysis of drinking water:

17. That the Commissioner of the Works Department, Metropolitan Toronto, be requested to identify any additional chemicals present in Toronto's drinking water at the most sensitive detection levels possible which are not included in regular analyses, by performing a complete gas chromatograph/mass spectrometer or electron capture scan on one set of drinking water samples in 1984.

National drinking water survey:

18. That the Minister of National Health and Welfare and the Minister of the Environment (federal) be requested to undertake a national survey of organic and inorganic chemicals in Canadian drinking water.

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5. WATER DISTRIBUTION SYSTEM

The watermain distribution system in Toronto is composed of three types of pipe: ductile iron, cast iron, and plastic. The newer ductile iron pipes are cement-lined, and since 1968 older, cast iron pipes have been improved with cement lining. Many watermains are approximately 100 years old, but generally they are still structurally sound (1). In the last two years, the Department of Public Works has started to install plastic pipes in some locations. Lead and galvanized iron pipes were used for service connections before 1950, after which copper pipe was phased in. Consideration is now being given to the use of plastic pipe for service connections.

In many water distribution systems, internal corrosion occurs, particularly in areas with 'aggressive' water. Corrosion can result in high concentrations of iron at the tap. Water drawn from Lake Ontario is only slightly 'aggressive', so this is not a serious problem in Toronto. The thin layer of cement inside many mains protects them from corrosion.

As mentioned above, many of the older service connections in Toronto are made of lead. In general, all residential properties other than apartments, constructed prior to 1950, have lead and/or galvanized iron pipe service connections. Lead connections are replaced when repair work is undertaken, but it is limited to that part of the connection between the watermain and the streetline. The section from the streetline to the building is the owner's responsibility (2).

Unfortunately, there are few data on lead concentrations at the tap (available data were obtained by the Department of Public Health). These show that lead concentrations increase up to six times following contact with lead piping. The adverse health effects of lead ingestion are discussed in detail in Section 7.

Another significant feature of the water distribution system is the use of plastic piping. This material has only been used recently in Toronto, although it has been the subject of some controversy in the U.S. Several potentially hazardous organic chemicals have been associated with the manufacture of plastic pipe, and residuals can leach into drinking water. There are few data on the chemical composition of such leachates. Organic chemicals that have been identified at concentrations above those in unexposed water include vinyl chloride, chloroform and other trihalomethanes, carbon tetrachloride, tetrachloroethylene, trichloroethylene and organotin stabilizers (3).

Adverse health effects resulting from exposure to the chemicals listed above have been documented. Vinyl chloride, chloroform, bromoform, carbon tetrachloride, tetrachloroethylene and trichloroethylene have been shown to be animal carcinogens. Both vinyl chloride and carbon tetrachloride have also been identified as human carcinogens, but whether average concentrations observed in water represent a significant hazard to the public has not yet been determined.

In 1978 the U.S. EPA conducted a survey of vinyl chloride monomer concentrations in the distribution systems of five cities using PVC pipe (4). The highest concentrations were measured in the newest system, and the lowest in the oldest. The vinyl chloride monomer concentrations found were comparable to, and in one case higher, than the concentration of 1 ug/L projected by the U.S. National Academy of Sciences to pose an upper limit excess lifetime cancer risk of one in a million for lifetime exposure (this risk level has been used as a guideline for exposure to carcinogens). This suggests that leachates from plastic pipe used for drinking water supplies should be more carefully investigated.

Flushing of plastic pipes has been suggested as one method of reducing residual chemical concentrations, but there are no conclusive data showing it is effective or showing how long it is required (5).

In addition to the potential problems associated with pipe leachates, contamination may occur from the PVC pipe cement solvents, used as joint sealants. However, joint sealants are not used in Toronto; instead, either high temperature welding or compression seals are used.

It is therefore recommended that the Department of Public Works investigate the extent of leaching of organic chemicals from plastic pipes. Such a study should include the determination of actual concentrations in areas of the Toronto distribution system where plastic pipe is used.

Samples of drinking water used for chemical analyses by Metro Works Department are usually taken at the filtration plants, rather than at the tap. When the Department of Public Health analyzed bottled water brands (Section 6.1), a sample of tap water was used for comparative purposes. If these results are compared to Metro Works' results for water samples taken at the filtration plant, it can be seen that concentrations of inorganics at the tap are generally equivalent to those measured at the filtration plants (see Section 4.3). But concentrations of silver and zinc were higher, and concentrations of boron, barium and copper were much higher than those at the filtration plants. Copper concentrations were probably higher at the tap because of a copper service connection, but it is unclear why the other inorganic concentrations mentioned are higher than at the filtration plant. It is therefore recommended that the Medical Officer of Health, in cooperation with the Commissioner of Public Works, City of

Toronto, be requested to prepare a proposal for systematic testing of chemicals in tap water in the City of Toronto and that other municipalities be encouraged to do the same.

Concentrations of trihalomethanes were very different at the tap and at the filtration plants. Three out of four trihalomethanes measured - chloroform, dichlorobromomethane and chlorodibromomethane - were higher at the tap. This suggests that trihalomethane formation is occurring in the distribution system. This effect has also been noted by Health and Welfare Canada which stated that "halomethane levels in water in the distribution system were found to be significantly higher than in water sampled at the treatment plant" (6). However, data from Metro Works Lawrence Reservoir suggest THM levels were not higher, when compared with those at the filtration plants. As trihalomethanes are potential carcinogens, it is recommended that the Metro Works Department study possible methods of reducing THM concentrations in the distribution system.

5.1 Recommendations

Plastic pipes:

19. That the Commissioner of Public Works, City of Toronto, be requested to investigate the extent of leaching of organic chemicals from plastic pipes and pipe sealants. Such a study should include the determination of actual concentrations in areas of the Toronto distribution system where plastic pipe is used.

Trihalomethane concentrations:

20. That the Medical Officer of Health, in cooperation with the Commissioner of Public Works, City of Toronto, be requested to prepare a proposal for systematic testing of chemicals in tap water in the City of Toronto, and that other municipalities be encouraged to do the same.

21. That the Commissioner of Works, Metropolitan Toronto, be requested to study possible methods of reducing trihalomethane concentrations in the distribution system.

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6. ALTERNATIVES TO MUNICIPALLY TREATED AND SUPPLIED DRINKING WATER

Recent concern shown for the quality of drinking water by the news media, government and the general public has resulted in increased use of alternatives to municipally supplied water. Preliminary results from the Department of Public Health's Community Health Survey indicate that approximately 7% of Torontonians drink or cook with bottled or specially treated water. Half of this 7% said they were concerned about chemicals in municipally supplied water and one-third said they preferred the taste of bottled or specially treated water. Alternatives to municipally treated and supplied drinking water are discussed below.

6.1 Bottled Water

In the last few years the consumption of bottled water has increased dramatically and it has been estimated that more than $4 million a year is spent on bottled water in Toronto. But it is also often assumed that bottled water is chemically purer than tap water.

In practice, bottled water sold in Ontario is not chemically analyzed, whereas the Metro water supply is analyzed several times a year. Therefore, much more is known about the chemical quality of tap water, and it cannot be assumed that bottled water is superior to tap water.

It is our opinion that bottled waters sold in Canada should be routinely chemically analyzed using the same criteria as are used in the analysis of tap water. Such analyses should be conducted by Health and Welfare Canada. It is further recommended that bottled water purity should be assessed using Health and Welfare Canada's Guidelines for Canadian Drinking Water Quality, 1978. At present, the quality of such waters is inadequately regulated by the Food and Drug Act.

In order to assess the chemical quality of bottled waters, the Department of Public Health and the Metro Works Department contracted for chemical (inorganic and organic) analyses of various brands of bottled water and samples of finished water. The results of these analyses have been presented in two reports (7,8). They show that the chemical quality of different brands of bottled water varied from worse than, to equivalent to, tap water.

6.2 Filters

Many point-of-use filters contain activated carbon and are intended to improve the quality of drinking water by removing undesirable tastes, odours and colours, and/or reducing or removing inorganic and organic contaminants. Most of these units also contain approximately 0.5% to 1% of silver to control the growth of micro-organisms. Although silver is included, it does not always have the desired bactericidal (bacteria-killing) effect (4).

Wallace and his co-workers (1) were among the first to demonstrate the proliferation of bacteria in filters, and Fiore and Babineau (2) showed the presence of high bacterial counts in effluent water after several days of non-use. Taylor et al (3) also showed that the numbers of bacteria in effluent water were higher than the corresponding influent water. This increase in bacterial numbers in effluent water has also been studied by the U.S. EPA (6).

Water filters have also been investigated by Health and Welfare Canada (4) which found that the total numbers of bacteria in the effluent rose steadily for three weeks of filter use, and then remained constant. Coliform bacteria were found to persist and proliferate on the filter. The nature of filter-colonizing bacteria has been reviewed by Health and Welfare Canada (5). On several occasions, they were found to be pathogenic. Pseudomonas aeruginosa and Flavobacterium have both been positively identified: P. aeruginosa can cause ear and urinary infections and Flavobacterium can cause meningitis in newborn infants. Similar bacteria have been identified in the effluents from granular activated carbon filter beds (see Section 9.4).

Despite the bacterial colonization of water filters, there are no data relating filters to observed health effects. However, it would be difficult to establish filter-grown bacteria as the cause of disease, and non-reporting of communicable diseases is widespread.

In May 1981, Health and Welfare Canada recommended that the sale of point-of-use filters be prohibited on the basis of demonstrated growth of bacteria. In September 1982 this position was reversed because the occurrence of adverse health effects had not been conclusively demonstrated. While it is true that epidemiological data are not available, the presence of human pathogens alone could be considered sufficient evidence to discourage the sale of these devices. Health and Welfare Canada recently developed a "code of practice" for point-of-use filters which include performance criteria, however this approach is not being successful. It is therefore recommended that Health and Welfare Canada be requested to examine the possibility of discouraging the sale of tap filtration devices in Canada.

The effectiveness of point-of-use filters in removing chemicals from water has been investigated by Health and Welfare Canada, as well as the EPA and the American Consumers' Union. A study of three filters by Health and Welfare Canada (4) showed that all three removed free available chlorine in municipally-treated water to below the detection level, but they only removed approximately 50 to 70% of the total available chlorine, and 4 to 33% of the total organic carbon, thus many organic chemicals pass through such filters. The EPA compared the percentages of total organic carbon removed in seven filter units, and the results showed that between 2 and 41% of the total organic carbon was removed, depending on the brand of the filter.

6.3 Distillers

Several types of stills can now be purchased to distill tap water. Many people assume that distilled water is pure, safe and wholesome, and that all impurities have been removed. But as with tap filters, there are disadvantages.

Far from removing all organic chemicals from the water, distilling can actually concentrate some of them. While non-volatile organics (those with a relatively high boiling point) will remain in the distilling vessel, volatile organics (those with a relatively low boiling point) will be carried over into the distilled water. Depending on the volume of water collected, these volatile chemicals may be more concentrated in the distilled water than in the original water. Furthermore, many of the non-volatile organic chemicals are naturally occurring decay products from plant and animal matter, while many of the volatile organics are synthetic chemicals.

Distilled water is felt by many to have a flat, unattractive taste. Although this is obviously not a hazard, taste is an important criterion for the public acceptability of any drinking water supply. It is therefore unlikely that these devices will gain large-scale popularity.

6.4 Reverse Osmosis

Small scale reverse osmosis (RO) units for domestic use are relatively new. They work by filtering out dissolved minerals using a semi-permeable cellulose acetate membrane. Approximately ten times as much water flows to the drain as is collected, however, reverse osmosis units are effective in removing metals and inorganic chemicals (80-95%).

The removal of organic chemicals is less easy to predict but will depend on such factors as the state of the membrane and the water pressure. Some reverse osmosis units also contain an activated carbon filter, so the removal of organics is accomplished by both carbon adsorption and reverse osmosis.

6.5 Recommendations

Bottled water:

22. That the Minister of National Health and Welfare be requested to chemically analyze brands of bottled water sold in Canada, on a regular basis.

23. That the Minister of National Health and Welfare be requested to assess the chemical quality of brands of bottled water sold in Canada using the Guidelines for Canadian Drinking Water Quality, 1978, as well as the bottled water regulations under the Food and Drug Act.

Tap filters:

24. That the Minister of National Health and Welfare be requested to reconsider the policy of permitting the sale of tap filtration devices in Canada.

References to Section 6

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7. DRINKING WATER STANDARDS

Standards for chemical concentrations in drinking water have been established in many countries to protect against the possible occurrence of adverse health effects. Such standards are set following an assessment of the potential health hazards of ingesting chemicals in drinking water, although technical and engineering considerations (i.e., what concentrations can be detected and what concentrations are feasible given existing water filtration and disinfection technologies) are also taken into account.

7.1 Assessing Health Hazards

Health hazards that may result from the consumption of drinking water are usually assessed using one or more of three methods: epidemiology; animal studies; and carcinogenesis or mutagenesis studies. Each of these methods is briefly discussed below.

Epidemiology

Epidemiology is the only direct means of demonstrating the occurrence of health hazards in human populations. It is the only one of the three methods that actually examines human health effects, rather than extrapolating from animals or other experimental systems. This means that epidemiology can only be used as a diagnostic technique (for the exposed population) rather than as a predictive technique.

It is difficult to identify human populations that have been exposed to only one hazardous substance. Therefore it is often necessary to correct for exposure to other substances, such as cigarette smoking and alcohol consumption. But even with correction for such multiple exposures it is often difficult to establish a cause and effect relationship for a particular chemical. It may also be difficult to measure the level(s) of the substance that the population has been exposed to (13). Often exposure levels within the selected population vary, or they may have varied over time. More frequently, exposure levels in the past have simply not been measured.

Another drawback of epidemiological studies is that the absence of a health effect does not necessarily prove there is no relationship between exposure to a particular chemical and health. This is also true for animal studies. In order to detect a rare health effect large sample sizes are required. Of course, the frequency of occurrence of a health effect will depend on the exposure level as well, so both the sample size and the exposure level can determine if a health effect is observed. Because large sample sizes increase the sensitivity of epidemiological studies, they are obviously to be preferred.

Epidemiological studies also tend to be long-lived because some health effects can take many years to develop (12). Some cancers have extremely long 'latency' periods (e.g., 15-20 years), and so do not manifest themselves until many years after the initial exposure. For example, the epidemiological follow-up study of the survivors of the Hiroshima and Nagasaki atomic bombs has been in progress since 1945, and is still going on. This means that migration in and out of the exposed population becomes important and studies should be restricted to long-term residents. Any thorough epidemiological study conducted in Toronto would have to consider the extensive immigration that has occurred in recent years.

Another feature of epidemiological studies is that many have been conducted on populations that have been exposed at work (i.e., occupationally exposed).. In the past many of these populations were largely comprised of healthy adult men, and so did not represent the usual mix of people in human populations. But some subgroups within a population may be more sensitive to chemical exposure than healthy adult men (e.g., children, infants and genetically susceptible subgroups). Therefore the results obtained from these studies may not be applicable to human populations generally. Recently, more epidemiological studies are being conducted with the general public, making such research more relevant.

Animal Tests

Animals are often used to assess the health hazards associated with exposure to chemicals. Rodents (rats, mice) are usually chosen because they are metabolically and anatomically similar to humans. However it is always necessary to extrapolate the health effects noted in animals to man and although correspondence is good, it can seldom be completely accurate. For example, benzene causes leukemia in humans but data from animals are equivocal. This shows metabolic differences can be important.

Another example of this is that small animals, such as rats and mice, are not as susceptible to toxic chemicals as humans. This is partly because chemicals do not persist as long in small animals as they do in large animals, such as humans, as they are metabolized faster. It is also because humans live relatively longer than small animals and so there are more cell divisions in a human lifespan than a small animal's lifespan. Therefore, there are more opportunities for the disruption of cellular replication and development. This can result in an underestimation of human health effects from animal studies (14).

Extrapolation can also be difficult because populations of laboratory animals are usually inbred and therefore genetically similar. As mentioned above, human populations are very varied and so comprise a much more genetically diverse population than laboratory animals. This can make animal to human extrapolations inaccurate as one would not necessarily expect the same response to chemical exposure from an inbred animal population as a mixed human population.

Another feature of animal studies is that the test animals are usually exposed to large doses of a single chemical. These conditions are unlikely to occur in human populations where doses are often small and involve more than one chemical. This means that it is often necessary to extrapolate from the health effects caused by relatively high doses (in animals) to those likely to be caused by relatively low doses (in man). In addition, little is known about how mixtures of chemicals interact with each other. When more than one chemical is present it is possible for their combined effects to be less than the sum of their individual effects (additive), or greater than the sum of their individual effects (synergism). Although we are rarely exposed to a single chèmical, little research is being done in this area (15). Some studies of short term feeding suggest synergism may not be a universal phenomenon (22,23). However, it is also necessary to conduct long-term feeding studies with mixtures of chemicals before conclusions can be drawn. Multi-generational studies to identify possible teratogenic effects of individual chemicals and mixtures of chemicals would also be helpful.

Animal studies on relatively small test populations also necessitate the extrapolation of results to much larger human populations.

Carcinogenesis and Mutagenesis Studies

Carcinogenesis and mutagenesis studies are usually conducted *in vitro*. This means that, in contrast to the two other types of studies mentioned, they are not conducted on living organisms. Usually either a particular cell line from a plant or an animal is cultured in the laboratory or bacteria are used. Therefore, it is necessary to extrapolate either from one particular animal or plant cell type to a whole human being (composed of many cell types) or from bacteria to humans.

The main advantages of this type of test are that they are relatively inexpensive and siuple to perform, when compared with the other methods outlined above.

Unfortunately, these short-term tests are only available for chromosome aberrations, carcinogenesis and mutagenesis. Health effects other than cancer cannot usually be predicted. Also, there is still some uncertainty about what a mutation of a cell's DNA actually means in terms of carcinogenesis. Research has shown that most mutagens are carcinogens which suggests that the ultimate cause of cancer is a mutational change in the DNA (16). Evidence also suggests that there is a correlation between the potency of a mutagen and its carcinogenic ability (24).

Although the correlation between mutagenesis and carcinogenesis is generally good, there are exceptions. For example, some chlorinated organic chemicals which have been found to be carcinogenic in man and animals, do not cause mutation in the best-known short-term test, the Ames test (using Salmonella bacteria). This suggests that the relationship between carcinogenesis and mutagenesis may not be simple.

Usually one or more of the three methods described above are used to assess the human health hazards of exposure to chemicals. Often short-term carcinogenesis and mutagenesis tests are conducted first and these are followed by animal or epidemiological studies. All the methods mentioned above have advantages and disadvantages but when used in combination, the results are more likely to provide an accurate estimate of human health effects.

The methods of hazard assessment outlined above represent the classical scientific approach, where the effects of one chemical are considered in isolation from all others. Yet, in the real world this situation rarely occurs, because every day we are exposed to a multitude of chemicals from many sources. As mentioned above, these can interact synergistically, additively or antagonistically. It is doubtful that science will ever be able to quantify all the risks associated with all the possible interactions and combinations, simply because they are too numerous. Given this situation, we must look for new ways to improve our assessment of hazards.

One possibility is the use of biological monitoring methods. This approach can assess the hazards associated with exposure to one or a mixture of chemicals. An example of a biological monitoring technique is the Ames test (mentioned above). The combined effects of all the chemicals present can be assessed without necessarily having to know the identities of the individual components. This is done by using concentrated drinking water as the test agent in the Ames test. This type of technique can also be used as a predictive tool to assess contamination, when chemical analysis could take many months to complete. These methods are currently being developed for use with drinking water and it is hoped that eventually the principle of biological monitoring can be incorporated into guidelines for drinking water.

7.2 Setting Standards

Once the health hazards associated with exposure to a chemical have been investigated, the information can be used to derive standards for drinking water. There are two ways of evaluating data: establishing "no observed effects levels", and risk levels (17).

No Observed Effects Levels

This method is used to set the Canadian drinking water guidelines (except for trihalomethanes and nitrilotriacetic acid) (2). Usually a concentration of the chemical being studied is found, below which there are no observed adverse health effects in animals. This concentration is then extrapolated to human health, allowing for such factors as body weight, the average daily consumption of drinking water, and how good the data are. A safety factor is usually incorporated, although not necessarily the same factor is used for all chemicals.

The use of "no observed effects levels" implies that threshold concentrations exist, below which there are no risks of adverse health effects developing. While thresholds have been demonstrated for many non-cancer health effects, it is not generally accepted that they exist for cancers. This is because a cancer is thought to be initiated by a mutational event in a cell's genetic material, which is then duplicated when the cell divides. Therefore, theoretically a single molecule of a carcinogen could initiate a cancer, and there would be no threshold doses for carcinogens. Although this view is generally accepted, some researchers feel that metabolic processes, such as detoxification, excretion, DNA repair and binding with other molecules, can prevent cancer initiation and progression. Though these mechanisms could increase the minimal amount of a carcinogen needed to induce cancer, the existence of threshold doses has not been satisfactorily demonstrated. In the absence of reliable data demonstrating thresholds, many regulatory agencies consider it more appropriate to use the risk levels method to set standards for carcinogens (1,18,19,25). As mentioned above, the Canadian drinking water guidelines for most carcinogens and non-carcinogens alike are set using the "no observed effects levels" method, and it is therefore recommended that, in future, use of the "no observed effects levels" method of standard setting should be confined to non-carcinogenic chemicals. It is also recommended that exposure standards for carcinogens and potential carcinogens should be set at zero, where possible. This approach has already been adopted for food additives in the U.S. in the Delaney Amendment. When a zero exposure level is not possible, standards should be set using the risk levels method.

Risk Levels

Animal and sometimes human epidemiological studies are used to estimate the risk of disease in a given population. This is often expressed as the mortality or morbidity per million individuals per lifetime (taken as 70 years) which will result from exposure to a particular chemical at a particular concentration. It is often necessary to extrapolate to lower exposure levels and larger populations, because most exposures resulting in observed health effects in test populations are relatively large. If such extrapolation is to be accurate, dose-response curves (i.e., a graph of health effects vs. exposure) must be constructed, by quantifying the health effects resulting from many exposure levels. It also often necessitates the extrapolation of health effects (responses) at high doses to those expected at low doses. The shapes of dose-response curves at low doses are often unclear and their scientific interpretation varies considerably.

Once the risk assessment is completed, it is necessary to decide what level of risk is acceptable, so that a standard exposure level can be set. The acceptability of risks has been the subject of much controversy. Clearly it is a matter of value judgments rather than scientific fact, and Whyte and Burton have suggested that, "... risk analysis does not necessarily reflect the emotions or values or preference of those at risk ... risk analysis stops at the boundary where risk acceptability comes into question" (3). Even the term 'risk acceptability' implies the purposeful acceptance of a risk (such as the presence of chemicals in drinking water) by those exposed to it. Yet, value judgments about what risks are 'acceptable' are not usually made in public in Canada.

In Canada, the National Research Council (NRC) refers to "virtually safe dose" as a one in a million lifetime risk of cancer (4). In the U.S., the lawful discharge of carcinogens into a receiving water was permitted for the first time in 1982. The discharge limits were set for quantities calculated to result in an increased cancer risk of 1 in 100,000 for each of the seven carcinogens licensed (5).

In the U.S., the EPA calculated the concentrations of various carcinogens which would cause an increased lifetime cancer risk of 1 in 100,000 (for lifetime exposure). It should be noted that these estimates are themselves subject to wide variation. These calculations are based on animal experiments and linear dose-response curves. In Table 11 these concentrations are compared to the "maximum acceptable concentrations" (MAC), set using the "no observed effects levels" method, as recommended by Health and Welfare Canada for several carcinogens (maximum acceptable concentrations are defined in Section 7.3).

Table 11

A Comparison of Maximum Acceptable Concentration Guidelines with Concentrations Estimated to Produce an Increased Lifetime Cancer Risk of 1 in 100,000

Carcinogen	MAC (ug/L)	Conc. in water estimated to produce a lifetime risk of 1 in 100,000 of cancer (ug)	Ratio
Arsenic	50	0.022	2,500
Cadmium	5	10	0.5
Chromium	50	50	1
Dieldrin/ Aldrin	0.7	0.0007	1,000
Heptachlor/ Heptachlor epoxide	3	0.0028	1,071
Lindane	4	0.186	22
Trihalo-methanes	350	1.9*	184

* Chloroform only

This table shows that the ingestion of 2 litres of water daily for a lifetime, containing the MAC for any one of these chemicals (except cadmium and chromium) would result in an increased lifetime cancer risk substantially greater than 1 in 100,000. Also, there is no consistency in the implied levels of acceptable risks. For example, the MAC for arsenic is 2,500 times greater than the concentration estimated to increase the cancer risk by 1 in 100,000, while the MAC for trihalomethanes is about 200 times more than the concentration estimated to increase the cancer risk by 1 in 100,000. In the U.S. this discrepancy also exists, but has been acknowledged by the EPA who have stated that "... levels are not intended to have a uniform safety factor" (6).

Current scientific methods of assessing environmental hazards are inadequate and we must be prepared to set standards with few data. When decisions are being made, the limitations of the scientific data should be stated and it may be appropriate to incorporate a wide range of public opinions into the decision-making process. It is therefore recommended that public participation should be encouraged when setting drinking water and other environmental standards. This could be done by incorporating a time period for public review and public hearings into the standard setting process.

An example of the incorporation of public opinion about water pollution into decision-making occurred several years ago in Zurich, Switzerland, where a plebiscite was held concerning municipal water treatment. Ninety percent of the population voted to spend additional tax dollars for upgrading the treatment system (using activated carbon) to protect the water supply from contamination by chemical spills in Lake Zurich (7). In Ontario, recent public opinion polls show that 99% of Ontarions feel that cleaning up the Great Lakes is a matter for concern. Seventy-five percent feel that this matter is a critical concern (8). A survey on attitudes toward Toronto's drinking water conducted for Pollution Probe in 1982 found that 60% of respondents were willing to pay an additional 5-$10.00 more per year for significant improvements in the quality of drinking water (11).

Already, hazard assessment methods are not the only means of setting drinking water standards.

In the U.S. the EPA established its standard for trihalomethanes on "a feasible level achievable with water treatmant technology" (9). Clearly, the public's health was not the only consideration taken into account.

In the Guidelines for Canadian Drinking Water Quality, 1978, the "objective concentrations" are described as "the ultimate quality goal for both health and aesthetic purposes", but in practice they usually are set at the detection levels for individual chemicals (2). Therefore, health protection is not a primary determinant in setting these guidelines (see pp. 55 and 86).

Therefore, some standards are set, at least partly, according to technical and engineering criteria, rather than health criteria. The Department of Public Health proposes that the primary determinants of drinking water standards should be the protection of the public's health and aesthetic concerns. If it is likely (based on animal or other studies and cautious extrapolative techniques) that a chemical may have adverse effects at concentrations below current detection levels, it may be necessary to establish a guideline, such as an objective concentration, below current detection levels. This would act as an incentive to improve the existing technologies and detection levels. At present there is little encouragement to improve current procedures and techniques through the standard (and guideline) setting process. Detection levels should be relevant to concentrations known or suspected to cause adverse human health effects.

An example of a similar situation is TCDD. Initially it was suspected that TCDD could have adverse human health effects (from animal studies) at concentrations well below the detection levels used at the time. Since then the detection levels for TCDD have become many orders of magnitude more sensitive. This remarkable technical achievement was accomplished in only a few years. The impetus for this achievement was brought about largely by pressure from the general public and the community of health professionals.

7.3 Existing Legislation

7.3.1 Federal Legislation

There are five federal acts which relate to water quality, though not specifically to drinking water quality. These are the Canada Fisheries Act, the Environmental Contaminants Act, the Canada Water Act, the Canada Shipping Act, and the Food and Drug Act.

In 1978, Health and Welfare Canada published Guidelines for Canadian Drinking Water Quality (2). This publication established two types of guidelines:

> Maximum acceptable concentrations - Drinking water that contains substances in concentrations greater than these limits is either capable of producing deleterious health effects or is aesthetically objectionable.
>
> Objective concentrations - These levels are interpreted as the ultimate quality goals for both health and aesthetic purposes.

The guidelines apply to physical, microbiological, inorganic, organic and radioactive parameters. Guidelines for physical, inorganic, organic and radioactive parameters are shown in Appendix 2.

However, the guidelines are not legally enforceable as regulations, and they are only recommended for a limited number of substances (forty-two), while the number of pollutants in the Great Lakes ecosystem is now over 800. The only organic chemicals for which guidelines have been established are nitrilotriacetic acid, some pesticides and trihalomethanes. Other groups and individual chemicals may be at least as potentially hazardous as those with guidelines. Therefore, there should be a more comprehensive range of standards which could be based on the U.S. EPA's list of priority pollutants.

In addition, the guidelines are based on data which have been superseded and the process for setting standards for carcinogens should be reviewed, as discussed in Section 7.2. It is understood that Health and Welfare Canada is currently reviewing the Guidelines for Canadian Drinking Water Quality, 1978. It is therefore recommended that the Minister of National Health and Welfare be requested to consider setting guidelines for a comprehensive range of organic chemicals, which could be based on the U.S. EPA's list of priority pollutants.

7.3.2 Provincial Legislation

The Ontario Water Resources Act is the main provincial statute which governs water quality. Under this act the Minister of the Environment "has the supervision of all surface waters and ground waters in Ontario" (section 15, subsection 1). Furthermore, he "may examine any surface waters or ground waters in Ontario from time to time to determine what, if any, pollution exists and the causes thereof" (section 15, subsection 2).

The Minister is also responsible for the water supply, and for ensuring that water quality is not (in his opinion) impaired by pollution. He can also set standards for the quality of drinking and other water supplies, sewage and industrial waste effluents (section 44, subsection 1h).

Implementation of this Act has been facilitated by a booklet entitled Water Management: Goals, Policies, Objectives and Implementation Procedures of the Ministry of the Environment published in 1978 (10). Specifically, the booklet outlines the following types of objectives.

Provincial Water Quality Objectives

The water quality objectives have been established on the basis of the protection of aquatic life and recreation in and on water. They do not apply to drinking water, and are usually based on "no observed effects levels".

Provincial Drinking Water Objectives

Ontario drinking water objectives were first approved by the Ontario Water Resources Commission in 1964. Since then, four revised editions have been published. The most recent set of Ontario objectives are shown in Appendix 2.

These objectives are not legally enforceable. As with the federal guidelines, they are set on the basis of either health or aesthetic concerns (or both).

Three types of objectives are defined:

> Maximum acceptable concentrations - These are applied to substances about which there are known or suspected adverse health effects.
>
> Interim maximum acceptable concentrations - These are applied to substances of current concern with known chronic effects in mammals and for which there are no established maximum acceptable concentrations.
>
> Maximum desirable concentrations - These are applied to substances which, when present at concentrations above the objective, are either aesthetically objectionable to an appreciable number of consumers, or which may interfere with good water quality control practices.

The Ontario drinking water objectives are very similar to the federal guidelines. They are not legally enforceable, and are prescribed for a limited number of substances.

7.4 Comparison of Canadian Drinking Water Guidelines with Chemicals Identified in Toronto's Drinking Water

Appendix 1 lists the maximum concentrations of all the chemicals that have been identified in Toronto's water at any one time between 1971 and 1983.

The maximum concentrations shown in Appendix 1 are compared with the drinking water guidelines recommended by Health and Welfare Canada in Appendix 2. This comparison shows that the guidelines were exceeded several times. However, guidelines are not set for all chemicals identified in drinking water.

"Maximum acceptable concentrations" have been exceeded on two occasions: cadmium (both raw and finished water), and mercury (raw water equalled the guideline, finished water exceeded it).

7.5 Comparison of U.S. and Canadian Drinking Water Regulations

In 1974 the U.S. adopted a National Safe Drinking Water Act (see Appendix 3), and National Interim Primary Drinking Water Regulations were subsequently adopted. These are currently being revised by the EPA in the light of the National Academy of Sciences report Drinking Water and Health (20).

In contrast, the Canadian drinking water guidelines are not legally enforceable unless promulgated as such by the appropriate provincial regulatory agency.

Both the U.S. and Canadian standards use a maximum exposure value although the U.S. "maximum contaminant levels" are defined as a lifetime limit at the lowest practical level representing a potential hazard, while in Canada the "maximum acceptable concentration" is defined as a safe level of a contaminant. In addition, the U.S. has promulgated secondary standards based on the aesthetic qualities of drinking water, while in Canada this concept is incorporated in the "maximum acceptable concentration".

As well as having a broader concept of standards (the recommendation of "objective concentrations") and an increased frequency of sampling, Canada also has a larger list of substances for which there are standards. There is no substance regulated in the U.S. that does not have a Canadian guideline. Additional substances with recommended guidelines in Canada include antimony, boron, cyanide, nitrite, uranium, nitrilotriacetic acid and several pesticides (see Appendix 2).

There is a strong similarity between the Canadian "maximum acceptable concentrations" and the U.S. "maximum contaminant levels" for inorganics. There are, however, two differences. One is cadmium (U.S. standard 10 ug/L, Canadian guideline 5 ug/L), the other is mercury (U.S. standard 2 ug/L, Canadian guideline 1 ug/L). For organics, the trihalomethane standard in the U.S. is 100 ug/L, and the Canadian guideline is 350 ug/L. This is because, although both countries used a non-threshold risk assessment method, Health and Welfare Canada did not include an analysis of a U.S. study of mouse exposure to chloroform. It was felt that the chloroform doses were so high as to be inherently toxic to the mouse liver, so that at lower doses there would be no liver damage and therefore no liver cancer (i.e., they hypothesized that liver damage resulted in cancer)(21). In addition, the Canadian guideline is set on health considerations (2) whereas, as has been mentioned, the U.S. standard is based on health and technical considerations (9). Another difference is that the U.S. standard is based on an annual average of quarterly sampling results, but the Canadian guideline is based on single samples.

Other standards for chloroform are lower than both the U.S. and Canadian standards for trihalomethanes. The World Health Organization has proposed a guideline of 30 ug/L and West Germany has proposed a standard of 1 ug/L.

7.6 Options for Improving Existing Canadian Legislation

Canadian and Ontario drinking water standards are in need of revision. This revision is necessary for two reasons; first, the proliferation of chemicals in our society, and second, the need to recognize the public's demand for increased involvement in environmental issues.

Since the Second World War there has been an unprecedented proliferation in the manufacture and use of synthetic chemicals. They permeate almost every aspect of our daily lives, but because many do not occur in nature, natural ecosystems do not have mechanisms to degrade them. This is seen, for example, in the persistence of DDT in the aquatic environment even though its production and use were restricted several years ago.

Water, being a major part of the natural environment, is obviously affected by persistent chemicals. Although the concentrations of these chemicals may not seem large, and in some cases may be below present detection levels, we should be cautious about their presence because of the uncertainties surrounding the possibility of health effects that could result from exposure to, not only the individual chemicals present, but also from exposure to synergistic interaction between chemicals.

Public demand for involvement in environmental matters extends to many activities of our society. We are frightened by the dangers of ionizing radiation, whether produced by industry or war. We are suspicious of the air we breathe and the products emanating from smokestacks. We wish to know more about the water we drink. In all these cases, we are involuntary recipients of environmental pollution, and in each case there is a wish to exercise some control. This wish is not unreasonable. That is why the Department of Public Health advocates public participation in setting drinking water and other environmental standards.

There are several ways in which existing legislation could be revised. Firstly, it would be possible to incorporate drinking water regulations into the Ontario Water Resources Act. This would have the advantage of not requiring any additional legislation. Secondly, a provincial or federal Safe Drinking Water Act could be introduced. In April 1982, such an act was introduced into the Ontario Legislature as a private member's bill, and Health and Welfare Canada is currently discussing the feasibility of a federal Act. Setting mandatory standards is complex. There is a danger in Canada that such standards will be a lowest common denominator. Enforceable standards have to be technically feasible. Funds must be made available for upgrading non-compliant facilities. The current situation must be adequately documented. Testing methods must be improved. While we tend to support mandatory standards, we recognize that much preparatory work remains to be done. We encourage Ontario and Canada to explore mandatory standards, and recommend that the Medical Officer of Health, City of Toronto, be requested to prepare a short report on the implications of mandatory drinking water standards for chemicals.

7.7 Recommendations

Setting standards:

25. That the Minister of National Health and Welfare be urged to consider confining the use of "no observed effects levels" method of standard setting to non-carcinogenic chemicals in drinking water.

26. That the Minister of National Health and Welfare be requested to recommend a zero level of exposure to carcinogenic chemicals, where possible. Where this is not possible, it is recommended that exposure levels to carcinogens should be set using risk levels, rather than "no observed effects levels".

27. That the Minister of National Health and Welfare be requested to develop mechanisms for encouraging public participation when setting drinking water and other environmental standards, by incorporating a time period for public review and public hearings before standards are finalized.

28. That the Minister of National Health and Welfare be requested to consider setting drinking water guidelines for a comprehensive range of organic chemicals. This could be based on the U.S. Environmental Protection Agency's list of priority pollutants.

29. That the Medical Officer of Health, City of Toronto, be requested to prepare a short report on the implications of mandatory drinking water standards for chemicals.

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8. POTENTIAL HEALTH EFFECTS OF CHEMICALS IDENTIFIED IN TORONTO'S DRINKING WATER

8.1 Inorganic Chemicals

Inorganic compounds, in particular trace metals, are ubiquitously present in raw and finished water. Their sources are either natural or associated with human activity, and can often not be identified. Natural processes contributing to the presence of trace metals in raw water include weathering, leaching and soil erosion. Decaying vegetation can also affect the levels of metals as many concentrate specific elements selectively. Some human activities which contribute metals to water include mining and manufacturing. In addition, corrosion of the water distribution system can add trace metals to finished water before it reaches the consumer (see Section 5).

The inorganic chemicals below have all been identified in raw or finished Toronto drinking water at the filtration plants, and are listed in Appendix 1. As mentioned above, there are few data on water quality at the tap.

Aluminium

Aluminium is a common, natural contaminant of our food and drinking water. It is also used extensively in cosmetics, deodorants and medicines. Small amounts of aluminium have been considered non-poisonous, although toxic syndromes have been observed in animals injected with large amounts. Typical symptoms include lethargy, epilepsy, anorexia and eventual death. Recent studies indicate that it may be toxic to certain neurons in the central nervous system, and there is limited evidence that an excess may be associated with Alzheimer's disease (6). No mutagenic, carcinogenic or teratogenic effects have been reported. It is unlikely that any health effects would result from aluminium present in Toronto's drinking water.

Arsenic

Arsenic is a relatively common water contaminant, albeit at low concentrations. Natural sources probably account for some of the arsenic in surface waters. It is also found in some pesticides and fertilizers (in particular, superphosphates) and is produced in non-ferrous metal ore (e.g., copper) smelting. The toxicity of arsenic compounds is extremely variable and depends on the species exposed, the chemical nature of the arsenical and the rate and duration of exposure.

Studies done in Silesia, Argentina and Taiwan suggest that elevated levels of arsenic in drinking water may be associated with an increased incidence of skin cancer (and perhaps other cancers).

Several other symptoms and diseases have also been associated with high levels of arsenic (up to 800 ug/L) in water supplies in Chile, Argentina and Taiwan: abnormal skin pigmentation, chronic coryza, hyperkeratosis, Raynaud's Syndrome (a vascular disorder), and abdominal pain were reported (1,2,3). However, no clinical or hematologic abnormalities were associated with elevated drinking water concentrations in Alaska (mean value of 400 ug/L), despite elevated levels of arsenic in the urine of exposed individuals (4). The generally better health and nutrition of Alaskan populations may play a role in the dissimilar response of this group.

Human mutagenicity studies have been conducted using in vivo and in vitro exposure. Both techniques have shown frequent structural and numerical aberrations to the chromosomes. Teratogenicity has been demonstrated in animals.

Arsenic concentrations in Toronto's water vary from less than the detection level to 9 ug/L, the highest concentration ever measured in finished water being 3 ug/L. This is between 30 and 300 times less than the lowest concentrations known to cause adverse health effects.

Barium

Barium occurs naturally in almost all surface waters. It is highly toxic when soluble salts are ingested. Studies on barium in drinking water found an increase in deaths related to cardiovascular disease in communities with levels of barium from 2-10 mg/L (7).

Concentrations of barium positively detected in both raw and finished Toronto drinking water vary from 1-520 ug/L (i.e., 0.0001-0.520 mg/L). 0.520 mg/L, the highest value reported, is approximately four times less than the lowest value for chronic exposure (2 mg/L) associated with elevated cardiovascular mortality.

Boron

Boron has been identified in both raw and finished drinking water. Its presence in surface water may result from erosion or from industrial effluents as boron is used in the manufacture of disinfectants and drugs.

Boron is absorbed from the gastrointestinal tract. Excessive ingestion results in gastrointestinal disturbances, skin eruptions and central nervous system stimulation followed by depression. These effects have been observed in human infants following a 300 mg dose. The maximum concentration that has been observed in Toronto's drinking water is 70 ug/L, giving a daily consumption of 0.140 mg, well below concentrations known to cause adverse health effects.

There is no evidence of carcinogenicity, mutagenicity or teratogenicity.

Cadmium

Cadmium is probably present in most surface waters at low concentrations. It is a by-product of zinc processing. It is also used in electroplating, pigment manufacture and as a plasticizer. The main sources of cadmium to Lake Ontario are probably atmospheric deposition and industrial effluents.

Acute cadmium poisoning has been reported on several occasions, including instances when cadmium-plated food and beverage containers were used, and when it was accidentally discharged into a river in Japan, causing "Itai-Itai" disease. Acute cadmium poisoning is associated with severe gastrointestinal disorders. Experimental data also indicate that zinc, calcium and possibly sodium can influence cadmium toxicity. There is evidence that chronic cadmium exposure can cause hypertension in experimental animals.

Statistically significant correlations have been found between cadmium concentrations and cancer at 9 sites, including sites associated with smoker's cancer (mouth, esophagus, larynx, lung and bladder) and colon cancer (2). The authors suggested that the association between cadmium and colon cancer was accidental, but the correlation with smoker's cancer sites was relevant. In a study in Alberta, an association was found between cadmium concentration and prostate cancer (8). This cancer site was not associated with cadmium in the earlier study. Cadmium is also known to be teratogenic in rats.

Positive reports of cadmium concentrations in Toronto's water range from 0.2-20 ug/L for raw water and from 0.1-10 ug/L for finished water. The highest concentration, 10 ug/L, was found in samples taken on May 20, 1982. This is double Health and Welfare's maximum acceptable concentration.

Calcium and Water Hardness

Calcium is ubiquitous in water supplies. The only significant sources are natural, through erosion of rocks and soils. Calcium is one of the two common elements that contribute to water "hardness", the other being magnesium. Water hardness is measured in mg/L of calcium carbonate ($CaCO_3$). Water with less than 75 mg/L of $CaCO_3$ is considered soft, and above this concentration as hard. Soft water tends to be more corrosive than hard water, so some trace metals are found in higher concentrations in soft water.

Evidence suggests that the incidence of cardiovascular diseases (heart disease, hypertension and stroke) is associated with water hardness (see, for example, reference 9) . Most reports indicate an inverse correlation between the incidence of cardiovascular disease and the degree of hardness. Several hypotheses have been advanced as to how this occurs. These mostly involve either a protective action attributed to such elements as magnesium and calcium, which are found in hard water, or harmful effects attributed to certain metals such as cadmium and lead, which are found in soft water. It has been estimated that, assuming a causal association between water hardness and cardiovascular disease, optimal conditioning of drinking water could reduce the cardiovascular mortality rate in the United States by as much as 15% (10).

Toronto's drinking water is considered "moderately hard", so the incidence of cardiovascular disease that could be associated with drinking water is probably low, although there is no way of demonstrating this.

Cancer risk has also been studied in relation to water hardness, usually as a secondary topic after cardiovascular disease. Cancer at several sites was negatively correlated with hardness in some studies. The combined results of these studies would suggest there is no general relationship between hardness and cancer.

Several studies have investigated the possible relationship between water hardness and congenital abnormalities, especially anencephalus and other central nervous system (CNS) abnormalities (see, for example, references 11 and 12). Many of the earlier ecological studies suggested a negative association, with higher rates of CNS malformations in areas of soft water, although a few reported no significant correlation. Recent case-control studies did not show a relationship between CNS malformations and water hardness or concentrations of 10 or more trace elements. The case-control data, therefore, indicate no consistent relationship between water hardness and congenital CNS abnormalities. However, the associations observed in several ecological studies suggest that further research is needed to clarify this situation.

There is inconclusive evidence relating carcinogenic, mutagenic or teratogenic effects with water hardness in animals or man.

Chromium

When chromates are present in water, it is usually the result of industrial pollution. Chromates have long been recognized as toxic, and although chromium is a health hazard, it is also essential to human health. Ingestion of chromates can result in gastrointestinal tract hemorrhage, and if inhaled they can cause cancer of the respiratory tract (13). Exposure can also cause other chronic effects such as skin ulceration and respiratory disorders. Chromates are known human carcinogens, but dose-response data are not sufficient to estimate the potential health hazard. The highest chromium concentration that has been measured in both raw and finished water in Toronto is 6 ug/L. Although the form (i.e., chromium or chromates) is unknown, this concentration is well below that associated with chromate toxicity. However, exposure to chromium should be zero, if possible, because it is a human carcinogen.

Copper

Copper is frequently found in surface water and some groundwater. It can originate from natural sources or from human activities. The water treatment process and service connections can produce higher concentrations in finished water and tap water, than in raw water. Copper is essential for the healthy growth and development of both plants and animals. Large doses can result in gastrointestinal irritation and toxicity. Copper ingested through drinking water represents a small proportion of the total ingested (10). A federal guideline is set for copper on taste rather than health considerations. The highest copper concentration that has been measured at the filtration plants is 145 ug/L.

Cyanide

Cyanides are used in many industrial processes and are found in effluents from metal processing industries and chemical plants. Many cyanides are soluble in water and some are volatile.

Cyanide is a rapidly-acting poison. Cyanogen chloride (formed by chlorination) has less acute oral toxicity, but it may be converted to the more toxic cyanide in red blood cells (10). The chronic toxicity of cyanide and cyanogen chloride is largely unknown, and there are no available data on the carcinogenicity, mutagenicity or teratogenicity of cyanogen chloride or cyanide. Concentrations of cyanide in Toronto's drinking water vary from below the detection level to 16 ug/L. Cyanogen chloride concentrations are not measured.

Fluoride

In Toronto, fluoride is introduced into the water supply in the form of hydrofluosilicic acid, as a preventive dental health measure (barring interruptions in availability of the chemical) at a rate of 0.8 mg/L to supplement naturally occurring fluoride. (Other sources of fluoride include: fertilizer in agricultural runoff, fallout of airborne fluoride from industry, fluoride in treated and untreated sewage, etc.). Levels of fluoride in Metro's water supply are maintained at approximately 1.2 mg/L.

In the twenty years since Toronto began fluoridating its water supply there has been a steady decline in the prevalence of tooth decay. For instance, the 1980 Annual Statement of the Department of Public Health notes that since 1964, the percentage of 5 year-old children born experiencing deciduous tooth mortality ("baby" teeth lost to decay) has dropped from 21.5% to 3.0%, while the percentage of caries-free 5 year-olds has increased from 32.8% to 65.5% (14). The only reported adverse effect of fluoridation in Toronto was that approximately 5% of the children showed tooth mottling, i.e., changes in the colour of tooth enamel. Tooth mottling increases in severity with amount of fluoride in water above 1 mg/L.

There is currently no scientific consensus on additional risks or benefits associated with fluoridation of water supplies. On the one hand, there is some suggestion that fluoride in water results in strengthened bone tissue and protection against osteoporosis (degenerative bone disease associated with aging). On the other hand, some research seems to indicate that chronic exposure to fluoride over a lifetime results in cumulative metabolic and biochemical changes. Additionally, fluoride has been shown to be a biological mutagen. The NRCC (National Research Council of Canada) has estimated that an acceptable daily intake of fluoride from food and beverages for a 70 kg "average" human is 2.3 to 5.8 mg per day (15). Sources of human fluoride exposure include food, beverages, drugs and prophylactic agents, cigarettes, water and air. Factors which increase vulnerability to fluoride toxicity include malnutrition, kidney disorders, diabetes, and water with low calcium and magnesium content (i.e., soft water).

Iron

Iron may be present in surface water as a result of human activities or from natural sources. It is generally present in the ferric state.

Iron is essential to the human diet, although inhalation of iron ore dusts containing impurities (e.g., silica, quartz) has been shown to contribute to an increased incidence of lung cancer and pneumoconiosis after prolonged exposure. There is no evidence of adverse health effects from the consumption of drinking water containing iron, but the presence of iron can cause a disagreeable taste and colour. Iron can also stimulate the growth of certain bacteria in water piping. The highest iron concentration detected in Toronto's water has been 20 ug/L.

Lead

Lead occurs in both raw and finished water and can leach into drinking water from household plumbing.

Studies indicate that infants and young children are more susceptible than adults. Excessive lead intake adversely affects three bodily systems; the blood protein synthesis system, the kidneys and the nervous system. Of most concern are the effects of lead on the developing nervous system and the effects of lead on behaviour in infants and young children. Adverse effects on behaviour and intelligence have been observed, but they have not been reported at blood lead levels of less than 50 ug/100 ml. In general, alterations in enzyme systems are the most sensitive responses to lead exposure; these have been reported in children with blood lead levels of 15-30 ug/100 ml (10).

Environmental and occupational exposure of adults to lead has been associated with premature births, miscarriages, and sperm abnormalities. There are no conclusive data demonstrating that lead is teratogenic in humans, but mutagenicity, carcinogenicity and teratogenicity have been demonstrated in animals. Lead should therefore be regarded as a potential human carcinogen, mutagen and teratogen.

The contribution of drinking water to the average daily human intake of lead can be significant. Some studies have shown a relationship between lead concentrations in drinking water and blood lead levels. Results of two studies in Scotland suggested high lead levels in drinking water may be associated with mental retardation in young children (16,17). However, because lead concentrations in drinking water can vary depending on when the sample was drawn (e.g., first-draw morning or daytime running), no conclusions can be drawn.

Lead is detected in about 10% of finished drinking water samples in Toronto. Exposure to lead should be minimized because it is a potential human carcinogen.

Magnesium

Magnesium is one of the most common elements in minerals, rocks, and soils, and most of its salts are very soluble in water. It is an essential mineral for human health.

Magnesium is commonly found in drinking water supplies, and its presence is not considered hazardous, or potentially hazardous, to health.

Manganese

Manganese, like magnesium, is essential for human health. The prevalence of manganese in drinking water is not considered a potential or actual health hazard, although toxicity has been reported following inhalation of manganese. Excessive concentrations of manganese in drinking water (above 50 ug/L) may give rise to taste and odour problems. Concentrations in Toronto's drinking water are approximately 1 ug/L.

Mercury

Mercury is one of the least abundant elements in the earth's crust, but it has many industrial uses. These include the electrolytic preparation of chlorine and caustic soda, uses in electrical apparatus, applications in mildew-proof paints, control of fungal diseases in seeds, bulbs and plants, and in dental amalgam.

Metallic mercury is poorly soluble in water, but some mercury salts are soluble. In the environment it is often found as methylmercury, following the transformation of inorganic mercury into organic methylmercury by microorganisms present in river and lake sediments. Mercury is usually found as methylmercury in drinking water.

Two major outbreaks of methylmercury poisoning have occurred in recent years, both in Japan. In both cases, fatalities were caused by industrial pollution of water resulting in fish and shellfish contamination. Drinking water contamination was not involved (18). Other cases of poisoning have been reported following ingestion of seeds previously treated with organic mercury compounds. Symptoms include kidney damage, intestinal hemorrhage and ulceration. There was also some evidence of teratogenesis.

There is no evidence that metallic mercury in drinking water poses a health hazard, as it is usually converted to methylmercury. Methylmercury concentrations should always be as low as possible.

Mercury has only been detected in 10% of (Toronto) treated water samples. However, one measurement exceeded the Health and Welfare "maximum acceptable concentration" of 1 ug/L (May 20, 1982).

Nickel

Most of the nickel found in water supplies originates from human activities. It is used in alloys, food processing equipment and fungicides.

Ingested nickel is generally not absorbed, although there is evidence that it may be an essential trace element for human nutrition. Toxicity studies have shown that nickel and its salts have a low animal toxicity when administered orally. It is not known to be carcinogenic, mutagenic or teratogenic in animals via ingestion, but epidemiological studies of workers in nickel smelters and refiners have shown a significantly increased incidence of lung and nasal cavity cancers from inhalation (19). Nickel concentrations in Toronto's drinking water are unlikely to cause adverse health effects.

Nitrate and Nitrite

Two health hazards are related to drinking water containing high concentrations of nitrate or nitrite: induction of methemoglobinemia, and the formation of carcinogenic nitrosamines. Toxicity of nitrate (NO3) occurs as a result of reduction to nitrite (NO2), which can occur in the stomach. Nitrite oxidizes hemoglobin to methemoglobin, which does not act as an oxygen carrier like hemoglobin. Death may ensue through oxygen deprivation. There is also evidence that nitrites can react to form nitrosamines, many of which have been shown to be carcinogenic in animals (10).

Generally, infants are more susceptible to nitrate toxicity because of their higher intake per unit weight. The assessment of maximum nitrate concentrations exhibiting no adverse health effects has been based mainly on known cases of infant methemoglobinemia, rather than the carcinogenic potential of nitrosamines. From these studies, no cases were reported when the drinking water contained less than approximately 10 mg/L of nitrate and nitrite (as nitrogen), much more than is found in Toronto's drinking water.

As mentioned above, nitrosamines have been shown to be carcinogenic in animals, and several epidemiological correlations have been reported for gastric cancer (21,22). The concentrations of nitrates vary from 90-110 mg/L in drinking water in areas where an increased incidence was reported. These are much higher than concentrations encountered in Toronto's drinking water, but nitrates and nitrites should be considered as potential human carcinogens present in our drinking water. A case-control study in 1982 indicated a possible teratogenic effect of elevated nitrate levels in drinking water (20). However, when compared with other Canadian municipalities, the incidence rate of developmental abnormalities in Toronto is low.

Potassium

Potassium is widely distributed in foods and water, but because concentrations in water are low compared to those in foods, the contribution of water to total potassium intake is small. Potassium is essential for healthy nutrition, and symptoms of deficiency include weakness, anorexia, nausea, vomiting and listlessness. On the other hand, excessive amounts of potassium can be toxic. Symptoms of toxicity include gastric irritation and ulceration (23).

There is no evidence of carcinogenicity, mutagenicity or teratogenicity. Average potassium concentrations in Toronto's drinking water are 1.2 mg/L, and are unlikely to cause adverse health effects.

Phosphates

Phosphorus, in the form of phosphates, is common to most foods. Their presence in water may be due to human activities (including the manufacture of detergents and fertilizers), or be present naturally.

Dietary deficiency is not known to occur in humans because of their widespread presence in food. Soluble phosphates are relatively easily absorbed and in large amounts, can cause nausea, diarrhea, gastrointestinal hemorrhage, ulcerations and cellular damage to the liver and kidneys (24). Concentrations in Toronto's drinking water are too low to cause any of these effects.

There is no evidence that phosphates are carcinogenic, mutagenic or teratogenic.

Selenium

Selenium is used in the manufacture of electronic equipment, pigments, glass and ceramics. It has noticeable effects on animals, either in deficiency or excess, and there is a relatively narrow safety margin. Until recently, selenium was classified as a carcinogenic agent by the U.S. Food and Drug Administration, but is is now permitted as an animal feed additive.

Selenium itself is relatively non-hazardous but the soluble salts may be toxic. Chronic exposure by ingestion or inhalation results in symptoms of depression, gastrointestinal disturbance, and nervousness.

Selenium is an animal carcinogen: liver cancers in rats have been reported (25). There is no evidence of mutagenicity, but there is some evidence of a teratogenic effect in chickens.

Arsenic appears to alleviate the chronic and acute effects of selenium poisoning. Mercury has the opposite effect, but selenium seems to act protectively against mercury toxicity. A relationship between cadmium and selenium has also been reported: cadmium-induced lesions in the rat can be prevented by selenium. Selenium also protects against the toxic effects of silver and thallium (10).

The highest concentration that has been detected in Toronto's drinking water is 7 ug/L.

Silver

Silver has bactericidal characteristics at low concentrations and therefore can be used as a disinfectant. It originates from natural sources and from industrial effluents. It has a low solubility.

Large doses of colloidal silver have been shown to be lethal in experimental animals, but only chronic effects have been reported in humans. These include a permanent blue-grey discoloration of the skin, mucous membranes and eyes. It is thought that this is caused by 2-25 years of industrial exposure (26). It has been estimated that approximately 2g of retained silver can cause the effect; this corresponds to 45 years of consumption of drinking water (2 L/day), at the highest concentration ever found in Toronto's water (67 ug/L). The average concentration is much lower than this.

There is no evidence of any beneficial effect derived from the ingestion of silver.

Sodium

Sodium minerals are present ubiquitously in the aqueous environment. Sodium in Lake Ontario could originate naturally, from industrial sources or runoff (in particular from de-icing salts).

Sodium concentrations control the amount of water in the body, and disturbances can result in hypertension, congestive heart failure, renal disease, cirrhosis and toxemia. The relationship between sodium and hypertension is the most fully researched of these. Reduced sodium intake will lower the blood pressure in hypertensive individuals, and there is some evidence that an increased sodium intake will cause hypertension. Dahl (27) investigated the correlation between sodium intake and the prevalence of hypertension among populations. Examples of populations with high sodium intakes and high incidences of hypertension include Honshu, Japan (27) and villages in Newfoundland (28).

There is no evidence that sodium is carcinogenic, mutagenic or teratogenic in man.

Concentrations of sodium in Toronto's drinking water are approximately 12 mg/L. As drinking water is not the major source of dietary sodium and concentrations in Toronto's drinking water are not high, it is unlikely that the ingestion of sodium in water contributes significantly to the incidence of hypertension in Toronto.

Sulphates (Inorganic)

Sulphates in surface waters originate from rainfall (particularly from air masses that have been in contact with industrialized or urban areas), rocks and waste discharges.

The major observed health effect of sulphate is its laxative action, with diarrhea occurring at concentrations greater than 1000 mg/L. The taste threshold for sulphate is between 300-400 mg/L.

Thorium

Thorium is widely distributed throughout the earth's crust so its presence in drinking water supplies is to be expected. Following absorption, thorium accumulates in bone but when compared with other dietary components, drinking water usually contributes less than 2% of the daily dietary intake. However, it is radioactive and radioactive elements are carcinogenic and mutagenic. As mentioned in section 7.2, there are risks associated with all levels of exposure to carcinogens. Therefore, exposure through the consumption of drinking water, and from other sources, should be minimized wherever possible.

Exposure to thorium dust can cause dermatitis, and there have been reports that thorium causes pathological changes in the spleen, liver and lungs (24). Concentrations in Toronto have ranged from less than the detection level to 14 ug/L. Existing data do not permit an extrapolation of adverse health effects to these concentrations.

Tritium

Tritium (^{3}H) is a radioactive isotope of hydrogen. Its presence in lake and other ecosystems is due almost entirely to nuclear weapons testing and releases from nuclear power plants. Tritium is assumed to be evenly distributed in body fluids and is thought to have a biological half-life of 12 days (its radioactive half-life is 12 years). However, some studies suggest its biological half-life may be as long as one or two years.

Tritium concentrations in Toronto drinking water are gradually increasing. This may be because nuclear plants such as Pickering, release more tritium as they age. Although concentrations are below the Health and Welfare Canada maximum acceptable concentration of 1,080 pCi/L/year, two-thirds of ingested tritium is thought to come from drinking water. Average concentrations in Toronto's drinking water are approximately 400 pCi/L, but existing data do not permit an extrapolation of adverse health effects to these concentrations.

Uranium and the Uranyl Ion (UO2)

Uranium is widely distributed throughout the earth's crust but uranyl found in Lake Ontario could also originate from effluents, as many uranyl derivatives are used industrially. Uranium is acutely toxic in large doses, causing kidney failure. Concentrations present in drinking water are unlikely to have any toxic effects. Uranium is also a radioactive element and therefore carcinogenic. The possible carcinogenic effects of uranium in drinking water have not been investigated.

Zinc

Zinc is found in the lake sediments rather than in solution. It originates from rocks and human sources, primarily pesticides and metallurgic wastes.

Zinc is considered essential to human health, food being the main source. Zinc deficiency is associated with reduced growth, decreased fertility and loss of taste. Patients with sickle cell anemia may be zinc deficient. Acute adverse effects of zinc include "metal fume fever", caused by inhalation of the fumes. Prolonged consumption of drinking water containing very high levels of zinc (40 mg/L) corroded from galvanized pipe has been associated with muscular stiffness and pain, nausea, loss of appetite and irritability. There is no evidence that zinc is carcinogenic, mutagenic or teratogenic, but it does interact with other metals and has a protective effect against cadmium and lead.

The highest concentration of zinc ever recorded in Toronto's drinking water, is 0.064 mg/L.

8.2 Organic Chemicals

The organic contaminants that have been identified in drinking water represent only a small proportion of the total organic matter present in water. Approximately 90% of the organic matter present in water is non-volatile (i.e., it will not evaporate) and only 5 to 10% of the non-volatile substances present have been identified. In the remaining 10% of the organic matter, about 90% of the substances have been identified.

Many synthetic chemicals (or those present in water as a result of human activities) in water are volatile or semi-volatile, whereas many non-volatile chemicals are naturally present. These often result from the breakdown and decay of plant and animal material, or from organic matter associated with soil particles and micro-organisms.

There is no evidence that naturally present organic chemicals cause adverse health effects. The organic chemicals below have all been identified in raw or finished Toronto drinking water at the filtration plants. As mentioned previously, there are few data on water quality at the tap (see Recommendation 20).

Pesticides: Aldrin, Dieldrin, Endrin, Chlordane, Heptachlor and Heptachlor epoxide

These insecticides are all derivatives of hexachlorocylopentadiene. Traces of them and their stable breakdown products are ubiquitous in the environment and are bioconcentrated in many species of animals, including humans.

The health hazards of these insecticides are subtle and complex. They are the most hazardous of all known pesticides, because of their persistence, ability to be stored in fat and effects on the central nervous system. Human illness and death have been reported. Symptoms include epileptic convulsions, incontinence, psychic disturbances, headaches and insomnia. The chronic effects of ingestion have been studied in animals, but "no observed effects levels" cannot be estimated for dieldrin, heptachlor and chlordane. Generally, very low doses administered over long periods of time affect the central nervous system, causing disorientation, loss of reflexes, and convulsions. Organ degeneration has also been observed.

All of the insecticides above are animal carcinogens, and should therefore be regarded as potential human carcinogens. Dieldrin is not mutagenic but no information is available on the others. Aldrin, dieldrin and endrin are teratogenic. Some evidence indicates chlordane is not teratogenic, and there is no information available on the teratogenicity of heptachlor or heptachlor epoxide. These pesticides have been only detected in one set of samples, although they are routinely tested for by the Metro Works Department.

BHC (Benzene Hexachloride)

Benzene hexachloride (BHC) is the common name used to designate the various forms of 1,2,3,4,5,6-hexachlorocyclohexane. The different chemical forms are called alpha, beta and gamma-BHC. The commercial insecticide lindane contains gamma-BHC.

Lindane is the most acutely toxic form of BHC. In large doses it stimulates the nervous system causing hyperirritability, incoordination, convulsions and death due to respiratory collapse. Under chronic conditions the beta form is the most toxic causing liver and kidney damage in rats. In humans, surveys of tissue for organochlorine residues frequently show the presence of beta-BHC, the most persistent form. Chronic liver damage has been found in workers exposed to BHC, DDT or both, for periods ranging from 5 to 13 years. In other cases of exposure to BHC or lindane, aplastic anemia has been reported, as has leukemia.

Evidence of mutagenicity is conflicting but BHC is carcinogenic in rodents (29). Evidence shows the induction of liver tumors in mice, alpha-BHC being the most carcinogenic form. A related study showed that PCBs promoted the induction of liver tumors by alpha and beta BHC, suggesting PCBs were acting synergistically (30). There is no available data on the teratogenicity of BHC.

BHC is the most frequently detected organic chemical in our drinking water (with the exception of trihalomethanes), but even so, it has been detected in less than 50% of water samples taken. However, exposure should be zero, because BHC is a potential human carcinogen.

Pesticides: Malathion

Malathion is an organophosphate insecticide. Generally, organophosphate pesticides are more acutely toxic but less persistent than organochlorines.

There are many recorded cases of malathion poisoning in humans, but if proper therapy is given, the chances of survival are good. It has a moderate acute toxicity. Chronic effects include disruption of the central nervous system. There is no information available on the mutagenicity or carcinogenicity of malathion, and evidence for teratogenic and reproductive effects is unclear. Malathion has only been detected in Toronto's drinking water at one filtration plant.

Pesticides: DDT and its metabolites

DDT has been used very extensively all over the world for malaria control and as an agricultural insecticide. Its use is now restricted in many countries. Because of its persistence, DDT, or its metabolites, DDE and DDD, are still found in aquatic systems and many animal species. Fish from Lake Ontario often contain DDT although it is only infrequently detected in Toronto's drinking water.

The acute health effects of DDT include convulsions, due to central nervous system disruption, and shortened lifespans (10). DDT has been shown to be an animal carcinogen, but it is not mutagenic in the Ames test. Teratogenic effects in animals have not been observed, but the thickness of bird egg shells is reduced by maternal DDT ingestion.

Pesticides: Atrazine

Atrazine is a widely used herbicide. No cases of human poisoning have been reported, and it has a moderate to low acute toxicity. Although atrazine itself is not mutagenic, some plants can metabolize it into a mutagen when they are sprayed. There are few data available on its carcinogenicity or teratogenicity. Only a trace of atrazine has ever been found in Toronto's water, so it is unlikely to cause adverse health effects.

Pesticides: Endosulphan

Endosulphan is an organochlorine pesticide. Unlike many other such pesticides, it does not bioaccumulate in large amounts in human tissues.

In large doses endosulphan disrupts the central nervous system, causing convulsions, and it has a high acute toxicity in animals. It is also an animal carcinogen, and must therefore be regarded as a potential human carcinogen. Endosulphan has been detected very infrequently in Toronto's water.

Pesticides: Mirex

Mirex is an organochlorine pesticide and a fire retardant. It is extremely persistent and can bioaccumulate in many animal species, including man. Its use is restricted in Ontario.

It has a very high acute toxicity and is carcinogenic and teratogenic in animals. Mirex has been detected very infrequently in Toronto's water.

Phthalic Acid Esters

Phthalic acid esters, such as diethyl hexylphthalate, have been used as plasticizers for resins and polymers such as polyvinyl chloride (PVC). They have been found in industrial effluents, leachate from landfill sites containing plastic wastes, and in emissions from municipal incinerators.

Following absorption through the gastrointestinal tract, phthalic acid esters become widely distributed in the body with a particular affinity for the liver. In general, they are eliminated and do not bioaccumulate. Three cases of human ingestion have been reported. Ingestion of 10g of diethyl hexylphthalate or dibutyl phthalate produced diarrhea, nausea, vertigo and toxic nephritis. Phthalic acid esters have a low chronic oral toxicity in animals, but the associated health effects are not well characterized.

Some phthalic acid esters are animal carcinogens, and they can be mutagenic and teratogenic. Diethyl hexylphthalate has been shown to be mutagenic in mice at ingested concentrations of 10 mg/kg/day. Teratogenicity has been demonstrated in many phthalic acid esters. Effects in rats included gross abnormalities, skeletal malformations and fetal deaths, the extent and nature of the effect depending on the type and concentration of ester administered. Dose levels ranged from 640 to 5,000 mg/kg.

Maximum concentrations recorded in both raw and treated drinking water are approximately 1 mg/L (i.e., a maximum daily consumption of 2 mg). The Ministry of the Environment suspects sample contamination is responsible for these unusually high concentrations.

Polyaromatic hydrocarbons

Polyaromatic hydrocarbons have already been discussed in Section 2 above. They have only been detected in Toronto's water by one study (see Appendix 1).

Phosphate esters

Organic phosphates such as phosphate esters are generally less persistent than organochlorines (such as DDT and PCBs). But their acute toxicity is high; they affect the central nervous system, causing convulsions, sweating, headaches and psychic disturbances. There are very few studies of the possible chronic toxicity of these compounds, although some are teratogenic and/or mutagenic. There is no information showing phosphate esters are carcinogenic. They have only been detected in Toronto's water by one study (see Appendix 1).

Trihalomethanes: General

Since the controversial study by Harris in 1974, showing an association between drinking Mississippi River water and incidence of cancers (32), more than 20 studies of organic chemicals in water and cancer have been conducted (see, for example, references 33, 34 and 35).

Many of the earlier ecological studies indicated a positive association between gastrointestinal and urinary tract cancers. This was often between bladder, colon, rectum or stomach cancers, and chlorinated or surface water sources. However, the use of aggregated cancer mortalities, lack of control for many confounding variables and reliance on indirect measures of exposure severely limit the interpretations that can be made from these associations. Five of the ecological studies utilized measured levels of THM or chloroform. Their findings were somewhat contradictory, and only bladder cancer was correlated with THM level in more than one study.

The case-control studies, which represent a refinement over the ecological studies, generally point to an association between cancer of the rectum, colon and bladder and chlorinated drinking water supplies (see, for example, references 36 and 37). Five different case-control studies observed some increase in cancer risk for users of chlorinated or surface water compared to users of unchlorinated or ground water. The risks were 1.2 - 2.0 times as great for rectal cancer, 1.1 - 1.6 times for colon cancer, and 1.0 - 1.7 times for bladder cancer. Some of these odds ratios were statistically significant. Three of the studies attempted to determine a dose-response relationship, but no clear trend was observed. This was partly because chlorine ingestion was not always well quantified.

Although these case-controlled studies represent an improvement over the earlier ecological studies, they suffer from several limitations. Measures of water quality were largely indirect (i.e., chlorinated vs. unchlorinated) and were measured for a community or area rather than for individual cases. Since death certificates were usually the source of information, data on previous residences or occupations were unavailable. Potentially important confounding factors were also not controlled for, especially smoking and dietary habits.

Thus, studies in several parts of the United States have observed an association between surface water, chlorinated water or high THM concentrations and cancer of the bladder, rectum and colon. However, all of the studies suffer from limitations and must be interpreted with caution. Support for the hypothesis of a relationship between THMs in drinking water and cancer of the bladder, colon and rectum, inconclusive as it is, comes rather from the relative consistency of findings among different studies than from the strength of the findings in any one of the studies.

Trihalomethanes: Bromodichloromethane

Bromodichloromethane is one of the four common trihalomethanes found in drinking water. Chlorination can give rise to the presence of numerous chlorinated organic species, but any bromine ions present may also react to form bromoform, bromodichloromethane, and other compounds.

There are few data available on the toxicity of bromodichloromethane. Acute effects in mice include anaethesia at 500 mg/kg. Postmortem examinations showed a discoloration of the kidneys, hemorrhaging of the adrenal glands and alterations in liver metabolism. There are no data available on the chronic effects of ingesting bromodichloromethane, however, it has been shown to be mutagenic in the Ames test (24). The carcinogenicity and teratogenic potentials of this compound are unknown.

The paucity of data on the health effects of this compound makes it impossible to assess the potential for adverse effects due to the consumption of Toronto's drinking water.

Trihalomethanes: Dibromochloromethane

There are also few data available on the toxicity of dibromochloromethane. Ingestion of dibromochloromethane by mice produced the same results as noted for bromodichloromethane.

There are no data available on the chronic effects, teratogenicity or carcinogenicity of this compound. It is mutagenic in the Ames test.

The paucity of data on the health effects of this compound makes it impossible to assess the potential for adverse effects due to the consumption of Toronto's drinking water.

Trihalomethanes: Bromoform

There are few data available on the health effects of bromoform ingestion in man. In mice, subcutaneous injections (1113 mg/kg) produced a decrease in liver function. Similar changes were noted for guinea pigs. Chronic effects of inhalation have been examined, disorders in liver metabolism and kidney filtration capacity were noted; the threshold concentrations being 0.05 mg/L. There are no available data on the carcinogenicity or teratogenicity of bromoform, but it is mutagenic in the Ames test, under conditions in which chloroform is not mutagenic (24).

Trihalomethanes: Chloroform

There is considerably more data on the adverse health effects of chloroform than on the three other trihalomethanes found in drinking water.

In humans, there is some evidence of reversible liver damage following chronic ingestion of a cough suppressant containing chloroform. Oral doses of 30 ml (44.6g) can produce severe but non-lethal poisoning. Ingestion of 200 ml (296g) was fatal. Ingestion of chloroform is toxic to the liver and kidneys, and there is some evidence that kidney toxicity may be genetically influenced.

The carcinogenic effects of chloroform have been examined in mice and rats. Several experiments have shown the occurrence of various forms of liver cancer in males and females in both mice and rats. The U.S. National Cancer Institute has investigated the dose-response relationship for chloroform. Positive correlations were found for epithelial tumors of the kidneys and renal pelvis in rats and liver cancers in mice. The estimated risks for mice and rats were within a factor of ten. The risks of trihalomethane ingestion from Toronto's drinking water are discussed in Section 8.3.

Chloroform is negative in the Ames test under conditions for which bromoform was positive. There is no available evidence of teratogenicity, however, rats and rabbit offspring had reduced birth weights following maternal ingestion of chloroform (10,24).

As mentioned in Section 4.1, trihalomethanes are only one group of potentially carcinogenic chemicals formed by chlorination. The majority are non-volatile and have not yet been identified.

Benzene

Benzene is produced in several industrial processes and is an intermediate in the production of detergents and pesticides.

Acute effects in man include nausea, giddiness and headaches while chronic exposure has been reported to produce thrombocytopenia, leukopenia, anemia and leukemia. While some animal studies are equivocal, the evidence for benzene inducing leukemia in humans is strong (10). There is also evidence suggesting that benzene can be mutagenic, inducing chromosomal alterations. There are also some indications that it acts as a carcinogen. There are no reports of benzene acting as a teratogen.

Benzene has only been positively detected once in Toronto's drinking water. The concentration was less than 1 ug/L.

Carbon tetrachloride

Carbon tetrachloride is extremely persistent in the environment and is largely insoluble in water. Its presence is due to industrial activity.

It is readily absorbed and large doses can cause liver and/or kidney damage. It has a relatively high acute toxicity. Carbon tetrachloride is an animal carcinogen, but is negative in the Ames test. No teratogenic effects have been observed (10). Carbon tetrachloride has only been detected in trace amounts in Toronto's drinking water, but exposure should be zero because it is a potential carcinogen.

Dichloromethane (Methylene chloride)

Dichloromethane is used in the manufacture of paint and varnish removers, insecticides, fumigants, and solvents. It can be produced during the chlorination of water supplies.

There is little information available on the health effects of dichloromethane ingestion, but it was not found to be teratogenic (10).

Hexachlorobenzene (HCB)

Hexachlorobenzene is widely used as a fungicide for cereal, vegetable and other crops. It is extremely fat soluble and HCB residues have been found in human adipose tissue and blood from different parts of the world.

The acute toxicity of HCB is relatively low, but human poisoning has been reported in Turkey. Some deaths resulted, but the main syndrome was cutaneous porphyria. The estimated dosage was approximately 50-200 mg/day, but the exposure time was unknown (38).

HCB is more toxic on prolonged exposure. Mortality and severe weight loss occur in animals receiving 500 mg/kg over 9-16 days. Pathological effects on the liver have been reported, as have neurotoxic symptoms (twitching, etc.).

There is no available evidence for mutagenicity or carcinogenicity; there is some evidence for teratogenicity.

HCB has been detected only infrequently in Toronto's drinking water.

PCB (Polychlorinated Biphenyls)

PCBs are mixtures of chlorinated biphenyls which were used in electrical capacitors and transformers. They are highly persistent and can bioaccumulate.

PCBs are liver toxins and can cause chloracne and peripheral neuropathy. It was suggested that an outbreak of "Yusho" disease was caused by the ingestion of PCBs in rice oil, but recent evidence suggests that the oil was contaminated with polychlorinated dibenzofurans (a related group of chemicals) (39). Symptoms of PCB poisoning include fatigue, fever, skin eruptions and increased skin pigmentation. Chronic effects include liver enlargement.

Some PCBs have been shown to be carcinogenic in rats (40), although there is no evidence of mutagenicity. The only teratogenic effect known to be caused by maternal PCB ingestion is darker skin pigmentation in the newborn.

Their presence in Toronto's water has been only very infrequently detected. Until more is known of their adverse health effects, their significance is uncertain. A recent report to the Local Board of Health (January 1984) has discussed the health effects associated with exposure to PCBs in greater detail.

Chlorobenzenes (Tetra- and Penta-)

There is little information available on the adverse health effects of tetra- or penta- chlorobenzenes. Tetrachlorobenzenes have a low acute oral toxicity; there is no information available on chronic toxicity, carcinogenicity, mutagenicity or teratogenicity. Pentachlorobenzene is a potential human teratogen.

Trichlorobenzenes

Trichlorobenzenes are used as lubricants in polyester dyeing and in termite preparations.

There is no evidence of adverse health effects in man, but animal data show trichlorobenzenes have acute and chronic toxicity. Symptoms of acute toxicity included convulsions and a decrease in physical activity. Skin studies with rabbits and guinea pigs showed some irritation after prolonged contact (10).

There are no available data on the carcinogenicity, mutagenicity or teratogenicity of trichlorobenzenes. Trichlorobenzenes have only been detected infrequently in Toronto's water. Until more is known of their adverse health effects, it is impossible to assess their significance.

TCDD (Tetrachlorinated Dibenzo-P-Dioxin) and Other Dioxins

TCDD occurs as an impurity in the herbicide 2,4,5-T and possibly 2,4-D. It is also a byproduct in many industrial chlorination reactions. It is a member of the dioxin family (there are 75 forms of dioxin) and is thought to be the most toxic synthetic chemical. TCDD decomposes photochemically, but is persistent, remaining bound to soil for more than a year after application. Dioxins are also known to be present in large amounts (approximately two tonnes) in the Hyde Park Niagara waste disposal site.

There is little known about the chronic or acute toxicity of the dioxin family generally, as research has concentrated on TCDD. Symptoms include pathological changes in the liver, weight loss and gastric hemorrhage. Chronic effects of TCDD ingestion include decreased liver and thymus weights, and growth retardation.

TCDD is negative in the Ames mutagenicity test. But it is carcinogenic, teratogenic and toxic to fetuses. Decreased birth weights, organ malformations, gastrointestinal haemorrhage, cleft palate and other abnormalities have been reported following TCDD ingestion at low concentrations (ug/kg).

The National Research Council of Canada has suggested that a "virtually safe dose" (at a risk level of one in a million over a lifetime) is between 2 and 6 picograms per day for a 70 kg adult (41). Assuming all TCDD exposure is from drinking water, this would give a maximum concentration in drinking water of between 1 and 3 pg/L (1-3x10   g/L).

TCDD has been detected in Lake Ontario on two recent occasions. It was first identified early in 1983, when concentrations of 0.017 and 0.028 parts per trillion were detected in the lower Niagara River and in a tributary to the Welland Canal, respectively. More recently, dioxin has been identified in the raw drinking water for St. Catharines and Mississauga. Neither TCDD nor any other dioxin has been identified in Toronto's finished drinking water.

Toluene

Toluene is formed in petroleum refining and coal tar distillation and is used in the manufacture of chemicals, dyes and medicines.

Acute human exposure to toluene results in narcosis and chronic effects include poisoning of the central nervous system. There are no data available on the mutagenicity or teratogenicity of toluene (10). However, toluene is an animal carcinogen. Toluene has only been detected once in Toronto's drinking water.

Xylene

Xylene is formed by the same processes as toluene and has some of the same uses. It has a relatively low acute oral toxicity, but there is little information about its long-term toxicity, its mutagenicity or its carcinogenicity. It has been reported to be teratogenic (10). Xylene has only been detected once in Toronto's drinking water.

8.3 Estimating the Health Effects of Toronto's Drinking Water

This report has identified some 83 chemicals which have been detected in Toronto's drinking water at some time since 1971. For the vast majority of these, our knowledge of their individual health effects is incomplete. Our knowledge of their combined effects is even scantier. Some studies of such combined (i.e., ecotoxic) effects have been done, but as mentioned in Section 7.1 they were only short-term (up to thirteen weeks). It is therefore recommended that Health and Welfare Canada be requested to undertake long-term and multi-generational feeding studies of chemical mixtures to determine the effects of exposure on health hazards such as carcinogenesis and teratogenesis.

Many chemicals have been detected in parts per billion and parts per trillion, but we cannot dismiss these seemingly low concentrations as being insignificant. Extrapolations of animal studies suggest these concentrations may be biologically significant for some chemicals. For others with unknown health effects we advocate a cautious approach be adopted to ingestion through drinking water. We simply do not know what the health effects are likely to be, or even if there are likely to be any (our epidemiological study did not reveal any evidence of a correlation between various cancers and birth defects and water mutagenicity - see Appendix 4). This is a source of frustration for everyone, but probably most of all to the ordinary citizen who hears conflicting views from different 'authorities'.

Discussions of the health effects associated with hazardous chemicals in drinking water have concentrated on cancer, mutagenesis, teratogenesis, birth defects and some short-term effects, such as disturbances of the central nervous system. This is because these are the types of health effects that have been studied. We should not preclude the possibility of the occurrence of other health effects which have not yet been studied in such detail. Other possible effects might include behavioural and psychological effects, suppression of the immune system and reproductive effects, such as changes in fertility rates. Although this report has concentrated on known health effects this should not be seen as implying that these are the only possible effects. It is therefore recommended that Health and Welfare Canada be requested to investigate the possibility of such health effects as behavioural and psychological effects, suppression of the immune system and changes in fertility rates, and their relationship with the ingestion of hazardous chemicals.

Compounding these difficulties is the widening gap between our ability to detect chemicals and our ability to interpret detected levels in terms of human health effects. Public officials are responsible for reporting new data to the public, but if their significance cannot be explained, the possibility of generating public alarm adds a new dimension to that responsibility. Different jurisdictions contribute to this problem by issuing different guidelines or standards. The public's interpretation is that one jurisdiction is saying that a given chemical concentration is safe, while another is saying it is unsafe. This severely threatens the credibility of government agencies in the public's eye.

Another problem is that statements asserting that our drinking water is 'safe' do not reassure the public. Although Toronto's drinking water meets the Health and Welfare Canada guidelines, this can no longer be construed as 'safe'. Safe implies an absolute freedom from risk and clearly water containing carcinogens, or even potential carcinogens such as trihalomethanes, is not free from risk. We suggest that the word 'safe' be eliminated from discussions on drinking water. Instead we need to educate the public on risks associated with toxic chemicals in drinking water. Such risks should not be imposed, but the public themselves should be involved in discussions about what risks are acceptable, and hence in the standard setting process itself.

Bearing in mind some of the difficulties outlined above we are advocating that Health and Welfare adopt a zero level of exposure to carcinogens, where possible. This is a conservative approach which, if applied to the Canadian drinking water guidelines, would provide the highest degree of public protection possible.

Therefore, it is impossible to estimate what health effects could be occurring in Toronto as a result of drinking water consumption. However, it is possible to estimate the increased cancer incidence that could be associated with the ingestion of trihalomethanes, and this is shown below.

These estimates are based on the amounts of trihalomethanes that would increase the lifetime risk of cancer incidence by 1 in 100,000 for lifetime exposure. They were derived by the U.S. EPA using animal data and linear extrapolations from test population sizes to 100,000.

Table 12

A Comparison of 1983 Average Concentrations of Trihalomethanes with Concentrations Estimated to Produce an Increased Lifetime Cancer Mortality Risk of 1 in 100,00

	1983 avg. conc. (42) (ug/L)	conc. causing increased lifetime cancer risk of 1 in 100,000 (43) (ug/L)	increased lifetime cancer incidence from Toronto's water per 100,000 per lifetime (assuming linear extrapolation)
Trihalomethane			
Chloroform	4	1.9	2.1
Dichlorobromomethane and dibromochloromethane	3.5	1.9	1.4
TOTAL	7.5	--	3.5

This suggests that the increased lifetime risk of cancer incidence due to the ingestion of trihalomethanes is approximately 3.5 per 100,000. This is 35 times greater than the one in a million level recommended by the National Research Council as being a "virtually safe dose" of a carcinogen. On this basis alone it is again recommended that the Metro Works Department investigate ways of reducing trihalomethane concentrations in Toronto's drinking water.

We would like to stress that this estimate cannot be scientifically supported. It is merely an estimate extrapolated from animal data and does not represent known cases of cancer. The use of this estimate does not imply that consumption of Toronto's water causes cancer, however it is intended to stress that there are risks associated with drinking water. Indeed, the epidemiological study discussed in Appendix 4 of this report failed to demonstrate a correlation between drinking water mutagenicity and cancer.

An incidence rate of 3.5 per 100,000 over a 70 year lifetime is equivalent to one case of cancer being attributable to trihalomethanes every three years in the City of Toronto. Obviously this figure is very small when compared to overall cancer (mortality) data. The mortality rate for all forms of cancer in the City of Toronto was 212 per 100,000 for 1981 (calculated from reference 3). Therefore, the risk of cancer incidence from trihalomethane ingestion is very small when compared to the overall cancer mortality rate.

8.4 Recommendations

Health effects

30. That the Minister of National Health and Welfare be requested to investigate the possible interactive multi-generational effects of long-term exposure to chemicals in drinking water.

31. That the Minister of National Health and Welfare be requested to conduct animal studies on the possibility of such health effects as behavioural and psychological effects, suppression of the immune system and changes in fertility rates, and their relationship with the ingestion of hazardous chemicals, particularly through drinking water.

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9. ALTERNATIVE TREATMENT SYSTEMS

9.1 Reasons for Considering Alternatives

Chlorine is the most widespread water disinfectant used in North America. Its popularity stems from its proven effectiveness as a biocidal agent in drinking and wastewater. Since chlorine came into use in water treatment in the early part of the century, serious waterborne diseases such as typhoid, cholera, dysentery and infectious hepatitis have all but been eradicated in North America.

Until very recently it appeared that while the public health benefits of chlorine in water treatment were enormous, its risks were minimal or non-existent. In 1974, however, researchers in the Netherlands and the United States independently concluded that chlorine reacts with organic matter (mainly humic and fulvic acids) in raw water to form chloroform and other trihalomethane (THM) compounds. (1,2). Subsequent surveys of United States drinking water supplies by the EPA, including the National Organic Reconnaissance Survey (NORS) in 1975, and the National Organics Monitoring Survey (NOMS) in 1976 (3,4), found trihalomethanes in nearly all chlorinated water supplies. Chloroform appeared in the highest concentrations, followed by bromodichloromethane (CHCI2Br), chlorodibromomethane (CHBr2CI) and bromoform (CHBr3). In all, a total of 72 compounds were identified by these studies.

Trihalomethanes are just as prevalent in Canadian chlorinated water supplies. Health and Welfare Canada (1977) found trihalomethanes in chlorinated drinking water supplies of 70 Canadian municipalities that were not present in raw waters (5). Similarly, the Ontario Ministry of the Environment (1977) surveyed 48 Ontario drinking water supplies for trihalomethanes and found an average chloroform concentration in treated waters from the Great Lakes of 0.31mg/L (6). Levels of chlorodibromomethane and bromodichloromethane were much smaller. Fewer than 10% of the 300 raw water samples showed detectable amounts of trihalomethanes.

Concern about trihalomethanes in drinking water was heightened by the discovery by the United States National Cancer Institute (NCI) in 1976 that chloroform is an animal carcinogen (7). Since trihalomethanes were first associated with chlorination of raw water, researchers have observed that chlorine probably interacts with organics in unfinished waters to form a variety of chlorinated compounds other than trihalomethanes. For example, carbon tetrachloride, several chloroketones, and chloral have been found in chlorine-treated water supplies that were not present in raw waters at the same locations (8).

The fact that chlorine has a propensity to interact chemically with contaminants in water to form compounds that are potentially hazardous to health has prompted researchers to study the mutagenic potential of treated drinking water. In Canada, the United States and Europe, investigators have found that chlorination of raw water increases mutagenic activity in finished water to varying degrees (9).

Recently doubts have emerged about the efficacy of present water treatment practices with regard to removal of many organic and inorganic chemical contaminants that are being discovered in North American water supplies. More than 800 individual chemicals have been identified in the Great Lakes ecosystem by the International Joint Commission (10). As analytic procedures to detect these chemicals become more sophisticated, scientists are discovering that some of these chemicals are not being removed from raw water by current methods of filtration and disinfection (see Section 4.3).

Thus, the reasons for considering alternatives to current water filtration/disinfection practices, especially chlorination, arise out of concern that conventional treatment processes are not removing potentially hazardous chemicals from drinking water. Moreover, there is mounting evidence that water chlorination itself results in formation of new chemicals in drinking water, notably chloroform, a known animal carcinogen. Levels of chloroform in Metro Toronto drinking water have varied from 1.9 ug/L to 41.3 ug/L over the past ten years.

9.2 Trihalomethane Reduction

At this time, more is known about trihalomethanes in drinking water than about any other group of chemicals. Thus a major thrust in the search for alternatives to present water purification practices is to find ways of reducing trihalomethane formation in water treatment (see Section 4.1 for discussion of trihalomethane formation).

In Drinking Water and Health, three approaches were suggested for accomplishing trihalomethane reduction: 1) elimination of precursors prior to chlorination; 2) removal of trihalomethanes following chlorination; and 3) substitution of alternative disinfectants for chlorine. Within each of these approaches several specific methods exist, but not all are viable. For example, of thirteen possible alternative disinfectants including chlorine, only three were deemed suitable for drinking water treatment by the National Research Council/National Academy of

Sciences. Factors determining suitability included: technological status, efficacy in eliminating bacteria, viruses and protozoan cysts, persistence of residual in distribution systems and practical applicability. (Appendix 5 contains a list of the thirteen alternative disinfection methods considered by NRC/NAS.) Discussion later in this report will focus on the three suitable alternative disinfectants chosen by NRC/NAS.

9.2.1 Elimination of Trihalomethane Precursors

Disinfection efficiency is increased and formation of trihalomethanes is reduced when organic matter is removed from raw water prior to chlorination. Traditionally, most surface water treatment systems such as Metropolitan Toronto's system, have included clarification processes to remove particulates from water. These processes - coagulation, flocculation, sedimentation and filtration - are effective also in removing humic and fulvic acids from untreated water. Depending upon the nature of organic matter, pH of the water and type of coagulant used, coagulation, for example, may typically remove anywhere from 25-60% of organic precusors prior to chlorination (8).

Another strategy for reducing trihalomethane formation is to minimize/eliminate chlorine dosages early in the treatment process. In fact, this approach was used in 1979 by scientists from the Ontario Ministry of the Environment studying effects of water chlorination on trihalomethane formation. They found that elimination of pre-chlorination from three Metro Toronto treatment plants resulted in reduced trihalomethane formation during the three-month study period. Bacteriological quality of finished water was not compromised by doing away with prechlorination, although operational problems associated with slime growth were attributed to absence of pre-chlorination (11).

Ozonation also may be used early in the treatment process as a means of eliminating organic precursors to THM formation. This approach is used extensively in Europe and recently has been successfully tested in a pilot plant study for the Ontario Ministry of the Environment (39).

Finally, another means of removing trihalomethanes prior to final chlorination is through the use of activated carbon. Activated carbon refers to a group of porous substances possessing adsorptive and catalytic properties which make them potentially suitable as chemical removal media in water. Activated carbon is used in water treatment systems as an adsorbent for suspended solids and for synthetic organic chemicals which may be found in raw water and/or formed during the treatment process.

Activated carbon may be used in granular form (GAC) or in powdered form (PAC), and often is employed in combination with other processes - clarification, ozonation or other disinfection procedures. In certain instances microbial growth is promoted on GAC (sometimes referred to as biologically activated carbon - BAC) to enhance removal of organic compounds in water through biodegradation.

A number of studies in pilot plants have demonstrated that activated carbon is effective in removing a large proportion of organic precursors (7), particularly in combination with clarification procedures. By eliminating many trihalomethane precursors, activated carbon reduces the probability of trihalomethane formation following post-chlorination.

There has been much discussion recently in the United States and Canada about the pros and cons of using activated carbon for drinking water treatment. A thorough analysis of the issue was undertaken by NRC/NAS for Drinking Water and Health. We will deal with the issue in more detail in Section 9.4.

9.2.2 Elimination of Trihalomethanes Following Chlorination

Removal of trihalomethanes after their formation is another option for controlling these trace organics in drinking water. In situations where elimination of pre-chlorination is not feasible, trihalomethanes may be removed from treated water prior to distribution using GAC, synthetic resin adsorbents, or aeration.

Granular activated carbon removes small compounds such as THMs from water less effectively than it adsorbs larger ones, such as humic acids and pesticides. (7,11). For this reason, the option of using GAC to remove trihalomethanes from water following chlorination does not seem to be a viable approach relative to alternatives that seek to prevent trihalomethane formation by eliminating organic precursors.

Resin adsorbents refers to a group of synthetic adsorbents. Some operate by removing ionic species through an ion exchange process; others are non-ionic, polymeric resins with porous surfaces which act through adsorption and absorption. Ion exchange resins have been used by electric power utilities for a number of years to remove humic matter from water. Although ionic resins do this effectively, there is evidence that they may generate carcinogenic nitrosamines in the process. Thus, use of such resins in drinking water treatment may be unsuitable from a health standpoint. Polymeric resins have been found effective in removing trihalomethanes and other small organics from drinking water, but not efficient in removing humic material. These non-ionic resins have been pilot-tested in only a few water treatment plants.

Information on health effects is scarce. To date, no potentially hazardous chemical by-products have been identified in water treated with polymeric resin adsorbents.

Technology for removing trihalomethanes from drinking water following chlorination appears not to be as advanced as that for preventing trihalomethane formation by eliminating precursor material. From a health protection standpoint it matters little which approach is adopted to the extent that THMs are absent from finished water and no new hazardous substances are introduced.

9.2.3 Alternative Disinfectants

A third approach to reducing trihalomethane levels in finished water is to substitute some other disinfectant for chlorine. To be a satisfactory substitute for chlorine, an alternative disinfectant must be able to destroy effectively waterborne microorganisms known to cause disease in humans. Moreover, any potential alternative to chlorine must be shown to be unrelated to formation of trihalomethanes in drinking water. Additionally, to justify the costs of switching to an alternative disinfectant, it must be evident that the alternative is not associated with significant health risks of its own.

As mentioned earlier, NRC/NAS evaluated thirteen potential alternatives to chlorine disinfection (see Appendix 5) and concluded that only three would be viable substitutes for chlorine in water treatment: ozone, chlorine dioxide and chloramines. These three methods have come under increasing scrutiny in recent years as potential substitutes for chlorine in drinking water. Each has been judged to be feasible for large-scale practical application; indeed, all three are used already in water treatment facilities throughout North America and Europe. Toronto's own water treatment system relies on chloramines for residual disinfection.

A subsequent section (9.3) will provide a review of these three alternatives with regard to their health implications. The review does not attempt to evaluate the feasibility of implementing the alternatives in Toronto. Such a task requires sophisticated engineering and economic analyses that are beyond the scope of this discussion. The review does attempt to point out benefits and limitations of each method from a public health perspective, and to evaluate the advisability of choosing one alternative over another, or of choosing an alternative disinfectant at all.

9.3 Review of Alternative Disinfectants

9.3.1 Ozone

Ozone gas is a powerful oxidizing agent used as a disinfectant in drinking water treatment because of its excellent bactericidal and viricidal abilities. Ozonation is used widely as a water treatment process in Europe, where it was introduced early in the century. Although the province of Quebec has 20 facilities using ozone to purify drinking water, use of ozone in North America water treatment is relatively rare.

Since ozone decomposes rapidly (within ten to forty minutes, depending upon pH and water temperature), it is generated on site at water treatment facilities by passing an electrical charge through a stream of air or oxygen.

Ozone may be used at different points in the water treatment process and for a variety of reasons. In European water treatment facilities uses of ozone include: iron and manganese removal, oxidation of organics, taste and odour control, destruction of coliform bacteria and viruses, and flocculation (13). Thus, ozone may be used early in a water treatment system for iron and manganese removal or flocculation; at an intermediate stage, following filtration, for oxidation of organics and preparation of biologically activated carbon columns; and near the end of the process for inactivation of viruses and bacteria.

Ozone is only used as a terminal step in water treatment when (a) residence time in the distribution system is brief; (b) the temperature of finished water is relatively low; and (c) finished water has low levels of dissolved organic carbon (which facilitates bacterial growth). Average levels of dissolved organic carbon in Toronto's water supply are approximately 2.5 mg/L. Because ozone does not provide residual disinfection it is rarely used as the terminal disinfection step in drinking water treatment.

The effectiveness and suitability on health grounds of any potential chlorine substitute will be determined by three principal criteria: (1) its ability to eliminate biological contamination; (2) its tendency to reduce or eliminate formation of trihalomethanes; and (3) its failure to create significant hazardous by-products other than trihalomethanes.

In terms of its biocidal efficiency, ozone outranks all other oxidizing disinfectants including chlorine. Ozone inactivates microorganisms, namely E. coli and important enteroviruses (e.g., polio viruses, coxsackie viruses, and echo viruses), extremely rapidly. In fact, ozone has been judged to be two to three orders of magnitude more efficient as a disinfectant than free residual chlorine (14). The effects of ozone on protozoan cysts such as Giardia lamblia are largely unknown. Since ozone decays rapidly it usually must be used in conjunction with another disinfectant to maintain disinfection throughout the distribution system.

Ozone does not form trihalomethanes in water. Under certain circumstances, ozonation reduces trihalomethane precursors by oxidizing humic matter. Research has shown that trihalomethanes may form when ozone is used in conjunction with free residual chlorine. At a neutral pH, ozonation followed by chlorination reduces chloroform production. In contrast, ozonation and chlorination at a high pH result in increases in chloroform concentrations relative to pre-treated water (15). (The pH of Lake Ontario water is neither low nor high, being just slightly above neutral.) Thus, the option of using ozone for primary disinfection must be carefully evaluated in light of water parameters, particularly pH.

Ozone reacts with organic matter in water. Relatively little is known, however, about its reaction products. Substances that have been identified as reaction products of ozonation are aldehydes, ketones, and carboxylic acids, thought to result from degradation of humic matter (16). There is speculation that certain potentially hazardous peroxides and epoxides could be formed by ozonation, but this hypothesis has not been verified with studies of ozone-treated water. Of the substances that have been identified, none pose acute health hazards at existing concentrations (8). Information on long-term health effects of ozonation is too sparse to permit conclusions.

Recently, researchers have begun to study directly the links between drinking water and cancer. In a study of concentrated Ohio River water sampled in May, one group of researchers found that ozonated water initiated approximately the same number of tumors in mice as chlorinated water; both initiated more tumors than untreated water. When another water sample was obtained at a different time of year (December), however, nearly five times as many tumors resulted from untreated water as from ozone or chlorine treated water. The latter produced only a fraction of the previous number of tumors (17). Unfortunately, the data do not permit speculation about which ozonation by-products might have been the tumor initiator, nor about why the presumed tumor initiator would have been less active/potent in water sampled and treated at another time of year.

A study conducted recently in the Netherlands, at a pilot plant in Dordrecht, investigated effects of various water treatment methods on mutagenicity of stored water taken from the Rhine and Meuse Rivers (18, 20). Results of Ames tests from one study showed that ozonation reduced mutagenic activity in raw water considerably, while chlorination increased mutagenesis (18). In a second study ozonation only reduced mutagenic activity when Salmonella typhimurium bacteria were metabolically activated; chlorination increased mutagenesis with and without activation (20). Specific mutagenic compounds were not identified nor were seasonal variations reported in either study. Similar results were found comparing ozone and chlorine treatment of water from the Arns River in Italy (19).

A recent study for the Ontario Ministry of the Environment, however, found no evidence of mutagenic activity in water samples from three Ontario water supplies treated variously with ozone, chlorine, chloramines and combinations of these. Winter, spring and summer samples were tested; metabolic activation of the bacteria did not alter the outcomes (39).

These findings do not allow for conclusions to be drawn regarding the mutagenic potential of raw water treated with ozone. To the present time, there have been no studies reported of human health effects of consuming ozonated water, although such research is underway in the Netherlands. It is clear that additional research is needed to identify specific mutagens associated with ozone treatment and to determine why ozone seems to reduce mutagenesis under some conditions and not others.

From a public health viewpoint, the potential benefits of ozone as a water treatment method are great enough that we would recommend that a comprehensive pilot testing program be set up by the Ministry of the Environment to evaluate the effectiveness of ozone and alternative treatments of water. Ideally, such a program would be designed to evaluate the health effects of ozone used in conjunction with other treatments (e.g., activated carbon). Relevant health outcomes would include organic compounds and levels of mutagenic activity, and microorganisms found in respective water samples.

9.3.2 Chlorine dioxide

Chlorine dioxide is a chemical oxidant used widely for bleaching textiles and wood pulp. In North America, chlorine dioxide was first used in large-scale water treatment in 1944 at Niagara Falls, New York, as a control for phenolic tastes and odours. Today, chlorine dioxide is used in approximately 85 water treatment plants in the United States for the purpose of removing iron, manganese, taste, odour and colour. In Europe nearly 500 plants use chlorine dioxide for primary and residual disinfection. Chlorine dioxide was used in Toronto for taste and odour control until 1968, when it was discontinued due to lack of effectiveness in controlling phenolic tastes.

Because of its explosive potential, chlorine dioxide typically is prepared at points of use. Although there are several ways of producing chlorine dioxide, the method usually used in North American water treatment is to combine sodium chlorite or sodium chlorate and chlorine in an acidic aqueous solution. Another method, used commonly in Europe, is to combine a strong solution of sodium chlorite with hydrochloric acid. These chemical reactions frequently produce chlorate ion as a side product, and often excess chlorine remains when reactions are completed. Solutions of chlorine dioxide in pure water can be stored for months at a time in closed containers. Chlorine dioxide is highly photosensitive, decomposing rapidly in the presence of light (8).

Like chlorine and ozone, chlorine dioxide may be used at any one of several points in the water treatment process. Used for pretreatment, chlorine dioxide effectively breaks down iron and manganese and reduces turbidity of water by approximately 10%. Because of its photosensitivity, chlorine dioxide does not control algae growth in open-air clarifiers and filters. Since algae control is a major reason for pre-oxidation in water treatment facilities, this limitation of chlorine dioxide can be a disadvantage in systems with uncovered clarifiers and filters. Chlorine dioxide usually is more effective than chlorine at removing tastes and odours from water, but less effective than ozone (21).

In both pre-treatment and intermediate stages of water purification, chlorine dioxide may be employed to destroy bacteria and viruses. It is a rapidly acting, effective disinfectant which inactivates 99% of coliform bacteria in less than two minutes at concentrations of 0.25 to 0.30 mg/L (8). Chlorine dioxide also effectively destroys common enteroviruses and pathogenic amoebae (22). Unlike chlorine, chlorine dioxide oxidizes microorganisms more effectively at high pH values. The efficiency of chlorine dioxide as a disinfectant decreases, however, as water temperature declines.

At least one study has found chlorine dioxide to be a more efficient disinfectant than chlorine in the presence of high levels of organic and nitrogeneous matter (23). Studies of by-products formed from reaction of chlorine dioxide with organic matter in water show that chlorine dioxide does not form trihalomethanes in chlorine-free water (8). Chlorine dioxide does react with organic matter, however, to form chlorinated aromatic compounds, chlorinated phenols, chlorinated quinones and chlorite ion. Research on reaction products of chlorine dioxide in water has been conducted primarily in laboratories. Only one study has been reported of compounds found in drinking water treated with chlorine dioxide. In this instance, Onio River water was found to contain aldehydes resulting from treatment. No trihalomethanes were found (24).

Relatively little is known about organic compounds formed during treatment of raw water with chlorine dioxide. Health research has focussed on chlorine dioxide itself, and on the most well-known reaction products, chlorite and chlorate. Chlorite is formed when chlorine dioxide reacts with organic matter in water. Chlorite also may occur as a reagent when chlorine dioxide is prepared in an aqueous solution. It is estimated by NAS/NRC that chlorine dioxide treatments intended to give a concentration of 1 mg/L could result in chlorite concentrations of 1 mg/L if there is inefficient utilization of sodium chlorite in the initial preparation of chlorine dioxide (8).

Health Effects

Concern about health effects of chlorite is based on evidence of oxidative damage to red blood cells. Recent reviews of research on health effects of chlorine dioxide indicate that chlorite interferes with the oxygen carrying capacity of red blood cells by forming methemoglobin in several animal species and humans (17, 25). Additionally, chlorite damages red blood cell membranes, depletes levels of glutathione and increases concentrations of hydrogen peroxide. These changes result in hemolytic anemia, and have been observed in rats with chlorite levels of 50 mg/L of drinking water daily for 30 days. Similar effects have been found with chlorine dioxide. In one study with rats, depletion of glutathione was observed within 15 minutes of administering 0.1 mg/L chlorine dioxide (26). This concentration is one tenth of the EPA's recommended maximum dosage for water treatment (1.0 mg/L). Continued exposure to chlorate has also been shown to depress red blood cell glutathione levels. The authors of one study concluded that, while levels of chlorine dioxide, chlorite and chlorate found in drinking water may not cause serious acute illness, relatively low concentrations of these substances reduce the body's ability to adapt to blood oxidizing agents (25).

Other toxicological research on chlorine dioxide and its by-products has shown that these substances interfere with DNA synthesis in intestines, liver and testes of rats at doses of 10 mg/L daily for three months (25). In addition, there is evidence that chlorine dioxide forms mutagenic compounds in water, but not as a result of chlorination of organic materials (27). The compounds found in this Dutch study of treated waters from the Rhine and Meuse Rivers were polar oxygen-containing organics rather than chlorinated organics.

At least one controlled study has been undertaken with human volunteers to determine: a) the acute physiological effects of increasing doses of chlorine dioxide, chlorite and chlorate on healthy humans; b) the chronic effects on healthy humans of consuming these substances for 12 weeks at 5 mg/L per day; and c) the physiological responses to chronic (12 weeks) exposure of chlorite by persons susceptible to blood oxidation (i.e., those deficient in glucose-6-phosphate dehydrogenase). Although the investigators recorded a battery of physiological and psychological measurements, no definitive health effects of chlorine dioxide and its by-products were found. The authors speculated that the duration of this study might have been too short for chronic effects to become apparent (28).

Epidemiological research on health effects of chlorine dioxide has been done with both adults and infants. A study which compared two groups of healthy adults - one exposed to chlorine dioxide disinfected drinking water, and the other to conventionally chlorinated drinking water - found no significant evidence of hematologic effects over a three-month exposure period (29). A study of mortality and morbidity of newborns in two similar communities, one of which chlorinated its water, the other which used chlorine dioxide, found greater incidences of premature births and greater weight loss after birth in the chlorine dioxide community (30). Rates of jaundice, birth defects and fetal and neonatal mortality did not differ between the two communities. The effects that were observed were attributed to oxygen stress resulting from blood oxidation by chlorine dioxide.

Chlorine dioxide and its reaction products, chlorite and chlorate are demonstrated blood oxidizing agents which may have adverse health consequences, particularly for infants and certain susceptible groups of adults. For this reason, use of chlorine dioxide in water treatment was banned recently in Denmark (31). From a public health viewpoint, these findings are compelling enough that we would recommend that chlorine dioxide not be considered as an alternative to chlorine for disinfection of Toronto's water supply.

9.3.3 Chloramine

When ammonia is added to treated water it combines with free chlorine and the resulting product is known as combined chlorine or inorganic chloramine. In Metro's treatment system ammonia is added following final disinfection, at a concentration of approximately 0.15 mg/l to combine with the 0.5 mg/l residual chlorine normally remaining following final disinfection (32).

Adding ammonia to form inorganic chloramine in treated water produces a more stable residual disinfectant than chlorine, lasting longer in the distribution system. Additionally, chloramines reduce tastes and odours associated with chlorophenolic compounds.

When ammonia reacts with hypochlorous acid (chlorine) in water, it may form monochloramine, dichloramine or trichloramine (nitrogen trichloride), depending upon the ratio of chlorine to ammonia, temperature and pH of the water. Ammonia can be added to water in initial treatment phases to prevent formation of taste- and odour-producing chlorinated phenols. (Some water supplies may already contain high enough concentrations of ammonia that no additional ammonia need be introduced during treatment.) When chlorine is added at a subsequent treatment phase, it first oxidizes reducing agents such as sulfides, sulfites and nitrites, then reacts with ammonia to form inorganic chloramines. When all available ammonia has been used, a free available chlorine residual develops which then oxidizes the previously formed chloramines. When all chloramines have been oxidized, the "breakpoint" for chlorine has been reached, meaning that available chlorine remains free and uncombined as a residual in treatment and distribution systems.

Ammonia also may be added after chlorine and chlorine-reducing agents, at the final treatment phase. This practice, which is the more common use of chloramine in North American water treatment, is designed to eliminate residual chlorine in favour of the more persistent chloramine residual for disinfection in distribution systems. This is the procedure used in Metropolitan Toronto water treatment.

As a disinfectant, monochloramine, the form occurring most commonly under typical treatment conditions, is less effective than chlorine as a bactericide and viricide (7). Greater doses and/or contact times are needed for monochloramine to achieve inactivation of bacteria and viruses equivalent to chlorine. Dichloramine is a better biocide than monochloramine, but not as effective as chlorine. Neither mono- nor dichloramine are thought to be very effective at destroying waterborne parasites.

Very little research has attempted to identify chemical reaction products of chloramines in water. Trihalomethane formation has been investigated, however, and appears to be negligible in comparison with chlorine treatment. The NORS study found that 10 communities using chloramines for disinfection had an average concentration of 19 ug/L trihalomethanes in comparison with 72 ug/L among 70 communities using breakpoint chlorination (8). Chloramines are less effective as chlorinating agents than hypochlorous acid. Therefore, they are less likely to chlorinate organic matter and produce chlorinated compounds such as trihalomethanes.

Health Effects

Health effects of chloramines have been studied very little. Like chlorine dioxide and its reaction products, chloramines oxidize red blood cells in humans. In fact, chloramines were implicated in two outbreaks of acute hemolytic anemia among uremic patients in hospitals using chloramine to purify dialysis water. Patients in a third hospital that used activated carbon filtered water for dialysis were not affected (33). When health effects of monochloramine were studied in rats which ingested up to 10 mg/L of monochloramine for 45 days, hematological damage did not occur. One reviewer concluded that chloramines represent much less of a hazard for hemolytic anemia than chlorite, except for dialysis patients who probably are particularly susceptible (17).

In addition to producing hemolytic effects, monochloramine is a weak bacterial mutagen. The U.S. National Cancer Institute is conducting long-term carcinogenesis bioassays on both monochloramine and dichloramine. In the estimation of NAS/NRC there is not enough information currently available to establish human Suggested No Adverse Reaction Levels (SNARL) for either chronic or acute exposure to chloramines.

At this time we have no reason to recommend any changes in Metro Toronto water treatment practices with respect to use of chloramines.

9.3.4 Other Alternatives

In addition to the disinfection alternatives described above, there are a number of other treatment alternatives to chlorine. Two methods in particular appear promising, but are not yet feasible for implementation on a large scale. These are ultraviolet irradiation and reverse osmosis.

Reverse osmosis, a technique used already for small-scale applications (e.g., point-of-use treatment), involves passing water through a semi-permeable membrane which traps contaminants. In small-scale applications reverse osmosis devices have been effective at removing inorganics from water; effectiveness at removing organics improves with increasing chemical size. Removal efficiencies vary depending upon the kind of membrane used and advances in membrane technology are expected to improve treatment effectiveness.

At the present time, reverse osmosis is impractical for large-scale application because of uncertain effectiveness. The technique holds promise. For this reason, research should be initiated into health effects of water treated in this manner.

Ultraviolet (UV) irradiation is a technique that has been used successfully in wastewater treatment. While UV radiation is an excellent biocide, its effect on chemical contamination has not been demonstrated. A practical problem with this technique which stands in the way of large-scale application for drinking water treatment, is that UV irradiation only impinges on water at, or near the contact surface. Thus, the demand for enormous volumes of water to be disinfected in municipal water treatment makes UV irradiation unfeasible as a disinfection alternative at this time.

9.4 Activated Carbon Adsorption

The Subcommittee on Adsorption of the U.S. National Research Council's Safe Drinking Water Committee defines activated carbon as "... a family of carbonacious substances that are characterized primarily by their surface area, pore size distribution, and adsorptive and catalytic properties" (Drinking Water and Health, Vol. 2, p. 269). Substances that are used commonly as sources of activated carbon are lignite, natural coal, and coke.

Carbon and other adsorbents have been used in water treatment since ancient times. Today in Canada and the United States, activated carbon is used in a handful of drinking water treatment facilities for taste and odour control. In European water treatment, activated carbon is used at approximately 100 plants, primarily for removal of organics from water supplies, and in some instances for control of chemical spills. Additionally, numerous pilot plant studies are underway in the United States to determine the suitability of activated carbon for treating particular water supplies.

The process that characterizes activated carbon removal is known as adsorption. Adsorption refers to attachment to a surface (adsorbent) by a substance (adsorbate) because it is more attracted to that surface than to the solvent in which it occurs (in this case, water). Total adsorption rarely occurs; rather, an adsorbate will distribute itself between carbon and liquid in an equilibrium state (12).

Many factors influence the adsorbability of a substance by activated carbon. In general, organic compounds are adsorbable while inorganic compounds are relatively inadsorbable. There is evidence, however, that certain trace metals (chromium, mercury) can be adsorbed by activated carbon (34, 35, 36). The less soluble a compound, the more adsorbable it usually is. As a rule, large compounds are less soluble. Thus, increasing size results in increasing adsorption. This may explain why trihalomethanes are not adsorbed well by activated carbon, while large natural organic compounds are adsorbed relatively well. (As the porous carbon surface becomes saturated and many pores are unavailable, adsorption of large compounds declines. This phenomenon of competitive adsorption will be discussed below.) In addition to these factors, adsorbability by activated carbon is influenced by polarity of adsorbates, pH and temperature of water, as well as pore size distribution, surface area and polarity of the adsorbent.

In North American water treatment, use of activated carbon as a granular filter medium is on the increase. Typically, granular activated carbon (GAC) is used following clarification and preliminary disinfection (pre-chlorination). Although GAC may be used as filter medium for particles, they are usually removed by clarification processes prior to GAC treatment (8). Granular activated carbon is arranged commonly in packed-bed columns through which water flows downward. When the carbon is saturated it may be restored to its original adsorbing state through thermal regeneration. In North American water treatment, GAC is infrequently regenerated.

In European water treatment systems GAC is used typically to reduce organic content of water prior to disinfection. This practice reduces disinfection demand (i.e., less disinfectant is required to achieve desired microbial quality), and reduces formation of chlorinated organics when chlorine is used as a disinfectant.

Often in European water treatment, GAC is used in combination with ozone for pre-treatment. Studies show that pre-treatment with ozone has the effect of encouraging microbial growth on activated carbon (12). Such biologically activated carbon (BAC) has a much longer life than ordinary GAC, often remaining active for several years before regeneration is required (8). Whether BAC removes organic compounds that would ordinarily escape treatment with GAC is open to question. It may be that pre-ozonation converts non-biodegradable to degradable organic compounds which are oxidized by bacteria present on activated carbon.

Enhanced removal of organics by activated carbon following ozonation has been reported for full scale treatment systems (Dusseldorf, Muelheim, and Rouen-la-Chapelle), and for pilot plant operations (Bremen, Amsterdam, and Morsang-sur-Seine). In these instances, specific organic compounds were not measured, but rather group characteristics such as total organic carbon (TOC). Without measuring ozonation products and their biodegradability, it is difficult to know if removal of organics in these studies was the result of oxidation by ozone or adsorption and biodegradation by BAC. Studies which looked at the ability of ozone and GAC to remove organic precursors to trihalomethane formation found that the ozone-GAC combination reduces trihalomethane formation potential significantly better than either ozone or GAC alone (8).

Activated carbon in its powdered form (PAC) is used extensively in North American water treatment for removal of taste and odour-producing organics. PAC usually is applied early in the water treatment process and dispersed by rapid mixers. Contact times vary depending on where PAC is removed (e.g., sedimentation basin, rapid sand filter). In general, more PAC than GAC is required to achieve equivalent removals. The same compounds are expected to adsorb on PAC as GAC. At the present time, however, little is known about removal by PAC of THM precursors, chlorinated organics and other synthetic organic compounds. Because PAC has a relatively short contact time in water, it does not support microbial growth. Currently, PAC is difficult and expensive to regenerate and is not recommended for large-scale application for purposes other than taste and odour removal (12).

9.4.1 Removal Effectiveness of Activated Carbon

There are certain public health implications of using activated carbon for drinking water treatment. First, it is important to determine how effective activated carbon can be at removing substances which have been identified as potential health hazards. Second, we must establish that activated carbon does not itself contribute to contamination of drinking water. Finally, microbial quality of water must be maintained in the process of chemical removal by activated carbon treatment.

9.4.2 Removal of Organics

Activated carbon has been shown to remove many organic compounds from water. A survey of research literature on activated carbon adsorption found data on 40 organic compounds suspected of being potential health hazards, including trihalomethanes, PCBs, PAHs and several pesticides (8). These compounds were adsorbable in activated carbon to varying extents. Adsorption of specific compounds varies depending, among other things, upon how long the carbon has been in use, what pre-treatment process is being used, and what other compounds are present in influent water to compete for space on the carbon surface. According to Benedek and Bancsi, 90% of organics in water can be removed by freshly activated carbon (12). Removal efficiencies decline over time as carbon becomes saturated.

For the most part, adsorption studies have been conducted in laboratories, although some have been undertaken with pilot plants, and a handful done in full-scale treatment systems. Adsorption of trihalomethanes has been studied in all three situations (12). These studies found that trihalomethanes were not adsorbed well after two or three weeks. Nevertheless, about 30% of trihalomethanes were removed by carbon at the Morsang-sur-Seine plant in France after two years of operation. Much of the research on activated carbon adsorption of organics from water has relied on composite or grouped parameters rather than specific organics. Particularly in full-scale treatment operations, organics are often measured as total organic carbon (TOC), chemical oxygen demand (COD), total organic chlorine (TOCl), dissolved organic carbon (DOC), etc. For example, Benedek provided data on organic removals from three European plants - in Dusseldorf, Morsang-sur-Seine, and Zurich (12). The data were presented as DOC, COD, and UV extinction (ultraviolet absorbance). Removals ranged from 15% to 40%.

Removal of organics from water by activated carbon may involve biodegradation as well as adsorption, if there is microbial activity in the carbon beds. As noted earlier, microbial activity may be promoted by pre-ozonation. According to NRC/NAS, however, the role of ozone in fostering microbial action is unclear and further research is needed to identify initiating factors (8). Research in pilot plants and full-scale systems has shown that microbial activity removes organics (measured by group parameters) from water for up to two years, without regeneration. Biodegradation takes longer than adsorption, however, and no evidence exists yet for biodegradation of specific organics. In fact, recent research indicates that long term organic removal by GAC is due mostly to slow adsorption rather than biodegradation (40). There is evidence from an EPA pilot plant in Cincinnati that trihalomethane precursors are altered by pre-ozonation in such a way that their subsequent removal by activated carbon (possibly through biodegradation) is facilitated.

There is a great need for additional research on activated carbon in full-scale operations to determine whether activated carbon removes specific organics that are potential health hazards. Additionally, future research efforts need to be aimed at identifying the process responsible for removal of specific compounds - biodegradation or adsorption.

9.4.3 Removal of Inorganics

In comparison with what is known about the ability of activated carbon to remove organic compounds from water, information about removal of inorganics is scant. A few studies have been undertaken to discover how well activated carbon adsorbs trace metals, specifically iron, mercury and chromium. Activated carbon appears to be an effective adsorbent for these heavy metals. In fact, NRC/NAS suggests that removal of these metals by activated carbon occurs as a result of catalytic activity of carbon, rather than adsorption. It seems that certain heavy metal ions oxidize in the presence of activated carbon so that their adsorption on activated carbon actually involves reduction of ions on the carbon surface, in addition to accumulation (8).

Since many trace metals are combined with organic substances in water, predicting how they will act in adsorption studies is extremely difficult. Much remains to be done before we have an adequate understanding of how to remove trace metals from water.

9.4.4 Activated Carbon as a Source of Contamination

Because of its immense surface area, activated carbon has a tremendous capacity for adsorption. Nevertheless, the number of pores on a given surface of carbon is finite. As more pores become "filled" and fewer remain, competition for space on the carbon surface occurs. Such competition results in displacement and breakthrough of compounds with low adsorbability. Displacement refers to removal from a carbon surface of a weakly adsorbed substance by one that is strongly adsorbable, and is influenced by relative concentrations of competing substances, their relative adsorbabilities, and diffusive properties.

Activated carbon does not react with chemicals as chlorine does to form new compounds. To the extent that activated carbon does not form such by-products it is not a source of contamination of treated water. To the extent, however, that activated carbon fails to adsorb certain potentially harmful substances because of saturation and competitive adsorption, it may be associated with contaminating treated water with displaced organics.

A number of studies of competitive adsorption in laboratories, pilot plants and full-scale treatment systems were reported in Drinking Water and Health (8). There are limited data on contaminants of concern (i.e., organics, inorganics). In general, activated carbon has been shown to be effective at removing potentially hazardous organics even when competitive adsorption occurs. There are, of course, exceptions. Pilot plant studies conducted by the U.S. EPA found chloroform, dichloroethane, and trichloroethylene in treatment effluents at levels exceeding influent concentrations. Whether displacement due to competitive adsorption or variable influent composition was responsible for these effects could not be determined from available data. Because of wide variability in adsorbability of organics, some competition is expected. Furthermore, seasonal changes in concentration and composition of influent contaminants influences effluent composition. Extended pilot plant studies with activated carbon are needed to monitor contaminants in treatment effluents (assuming they are substances of concern to health), and to determine if they result from variations in influents idiosyncratic to a particular water supply or from displacement due to competition.

The other possibility for contamination of water treated with activated carbon is that microbial activity on carbon surfaces may produce toxins. Two mechanisms have been suggested: biodegradation of certain organic and inorganic chemicals into hazardous compounds that do not adsorb, and colonization of carbon columns by pathogenic microorganisms (e.g., enteric bacteria) and endotoxins, which may slough off and appear in effluents. These possibilities have not yet been observed to occur in GAC treatment. Breakdown products or organics and inorganics in effluents of GAC treatment have not been sufficiently studied to rule them out as a health concern. The possibility of pathogenic microorganisms is more easily ruled out. According to a recent review, the fact that there have been no disease outbreaks associated with extensive GAC treatment in Europe suggests that pathogenic microorganisms and toxins are not a problem (37).

Much work remains to be done in terms of identifying specific compounds and microbes in GAC treatment effluents. There is evidence, however, relating to overall toxicity of GAC-treated water as measured by the Ames test for mutagenicity. In a study of mutagenic activity of drinking water in the Netherlands, water samples in 13 out of 18 cities displayed mutagenicity. When water in several cities was treated with granular activated carbon, mutagenic activity was eliminated. This effect contrasted with results of treatment of the same waters with ozone and powdered activated carbon, which only reduced mutagenicity (18). Keeping in mind problems associated with the Ames test, we may infer from these results that the process of GAC adsorption probably does not produce mutagenic contaminants, and in fact probably removes such mutagens as are present in treatment influent.

9.4.5 Microbial Quality of Water Treated with Activated Carbon

An objective of water treatment that has to be preserved in the search for alternatives to conventional treatment is that finished water must be free of microbial pathogens. Thus, consideration must be given to how activated carbon affects microbial quality of water.

Activated carbon does not possess disinfecting properties. Nevertheless, GAC can improve disinfection efficiency of chlorine, chlorine dioxide and ozone by reducing the organic content of water that is about to be disinfected. GAC has been shown to effectively reduce disinfection demand and contact time needed for disinfection of E. coli (38).

On the other hand, we have noted that microbial growth on GAC beds is common and that extensive growth can result in organisms sloughing off into treatment effluents. Concerns have been raised about pathogenic microorganisms finding their way into finished water in this way. Studies have been done of bacterial quality of GAC-treated water. To date, the most common bacterial strain found in GAC beds and effluents is Pseudomonas, an "opportunistic" pathogen which was found in many but not all of the effluents tested in 13 studies reported in Drinking Water and Health. Fecal indicators (e.g., coliforms), have not been found in GAC treatment effluents, nor have Salmonella, Shigella, Vibrio or Yersinia enterocolitica. Moreover, frequent backwashing is said to counteract largely the problem of bacterial colonization on GAC beds (8).

9.4.6 Activated Carbon Pilot Testing

As concern mounts regarding chemical contamination of drinking water and failure of conventional treatment systems to eliminate chemicals, pressure to consider activated carbon has increased. The U.S. EPA has been conducting pilot studies in several locations for more than a decade. Now the first proposals for full-scale GAC treatment facilities designed to control chemical contamination are under review in Cincinnati, and a $4.2 million full-scale pilot plan (3 million gal/day) is being constructed in New Orleans.

In relative terms, Canada lags far behind in efforts to establish the effectiveness of GAC and other alternatives to conventional treatment. It is because of this that we have recommended that Health and Welfare Canada be requested to consider initiating a research program to investigate alternatives to conventional treatment methods (see Section 4). One of the first pilot plant studies of GAC in Canada is about to be undertaken by the Ontario Ministry of the Environment (MOE), which recently announced its intention to conduct such a study in the Niagara region.

The aim of the MOE's study is to re-examine current treatment processes with regard to chemical removal by optimizing conventional treatment and combining it with GAC. The project will begin with bench studies which will be scaled up eventually for application in pilot plants. The study will investigate removal of organics by GAC following optimized treatment. Factors that will be varied to determine their influence on treatment effectiveness include: pre-chlorination, filtration rates, coagulant types, sedimentation times, mixing speeds, depth of carbon beds and GAC type. There are no plans to study alternative disinfectants such as ozone or chlorine dioxide.

This MOE study is a much needed first step in reviewing Canadian water treatment practices in light of water quality data. Many of the gaps in our knowledge of how conventional treatment and its alternatives affect drinking water quality are based upon factors idiosyncratic to particular water supply situations (e.g., composition and concentrations of contaminants, seasonal variables, pH, water temperature, etc.). There is a great need for data regarding treatment effects on lower Great Lakes water supplies. We see data gathering as a role for all levels of government.

We hope that this landmark opportunity will be fully exploited by the MOE. For example, it would be more useful in the long run to have data about effects of alternative disinfectants (i.e., ozone, chlorine dioxide) than simply to have additional information on chlorine, the treatment effects of which are well known. In light of a growing trend towards combined GAC-ozone systems, the MOE might consider capitalizing on the opportunity to study this treatment combination. Given concerns about ozone raised in Section 9.3.1, we would like to see particular emphasis on organic compounds and mutagenicity in GAC-ozone treated water.

As this study is designed to be a test of how conventional treatment processes perform when they are optimized, the most rigorous testing conditions should be used. In other words, tests should be conducted under worst case conditions. In Ontario, the worst case situation for drinking water from a surface supply source is thought to be Niagara-on-the-Lake. We view this study as an important development in Canadian water quality matters. We encourage the MOE to make full use of the chance to address questions that otherwise will remain unanswered for many years to come.

9.5 Recommendation

32. That the Minister of the Environment for Ontario be requested to consider initiating a comprehensive field study to evaluate alternative disinfection and filtration techniques and report back to the Local Board of Health. Such a study could include evaluations of the effectiveness of ozone (as a disinfectant and in eliminating organics) and granular activated carbon. It is further recommended that combinations of alternative technologies (for example, granular activated carbon and ozone) and combinations of alternative and conventional technolgies (for example, granular activated carbon and chlorine) be evaluated. It is also recommended that this study be undertaken in collaboration with the Metro Toronto Works Department, using Toronto's drinking water supply, and the results be analyzed in consultation with the Medical Officers of Health for Metropolitan Toronto.

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APPENDIX 1

Maximum Concentrations of Chemicals Identified in Toronto's drinking water 1971-83

	Reference	Highest conc. in raw water (ug/L)	Highest conc. in finished water (ug/L)
Inorganics			
Aluminium	1	100	250
Arsenic	2	9	3
Barium	2	520	520
Boron	2	80	70
Cadmium	2	20	10
Calcium	3,2	38000	42000
Chloride	2	--	30000
Chromium	3,2	9	6
Copper	2	300	145
Cyanide	2	26	16
Fluoride	2	--	880
Iron	3,2	14	20
Lead	2	15	10
Magnesium	3,2	8500	10100
Manganese	4	--	6
Mercury	2	1	1.1
Nickel	2	150	11
Nitrate/ nitrite	3,2	455	1900
Potassium	2	--	1500
Phosphate	2	--	30
Selenium	2	6	7
Silica	2	--	1500
Silver	2	50	67
Sodium	2	--	13000
Sulphate	2	--	30000
Thorium	2	13	14
Uranyl	2	7.5	3.2
Zinc	2	42	64
Pesticides			
Aldrin/Dieldrin	2	0.002	0.002
alpha BHC	1,5	0.015	0.020
beta BHC	2,2	0.010	0.010
gamma BHC	1,2	0.020	0.002
Heptachlor epoxide	2,6	0.002	0.001

Malathion	2	--	195*
DDT and metabolites	8,4	0.016	0.002
Endrin	8	0.005	--
Endosulphan	8	0.002	--
Atrazine	9	--	trace
Chlordane	8	0.002	--
Mirex	8	0.005	--

Phthalates

Bis (2-ethyl hexyl) phthalate	2	1100*	1000*
Di-n-butyl-phthalate	2	1.3	1.4
Di-n-octyl-phthalate	2	92.8	3.9

Polyaromatic hydrocarbons

Naphthalene	2	--	0.3
Methyl naphthalene	5	--	0.02
Dimethyl naphthalene	5	--	0.01
Trimethyl naphthalene	5	--	0.002
Biphenyl	5	--	0.011
Bibenzyl	5	--	0.005
Fluorene		--	0.0006
Phenanthrene	5		
Anthracene	5	--	0.009
Fluoranthene	5	--	0.005
Pyrene	5	--	0.006
Methyl Anthracene	5	--	0.006
Stilbene	5	--	0.001
Fluorenone	5	--	0.010
Anthraquinone	5	--	0.008
Aggregate PAH	5	--	0.150

Phosphate esters

Triethyl	5	--	0.013
Tri-n-butyl	5	--	0.029
Tri-2-chloroethyl	5	--	0.012
Tri-1,3-dichloropropyl	5	--	0.004
Triphenyl	5	--	0.004

Tributoxyethyl	5	--	0.033
Tricresyl	5	--	0.001
Trihalomethanes			
Bromodichloromethane	2	15.2	42
Bromoform	2	--	3
Chloroform	2	29	41.3
Dibromochloromethane	2	5.5	6.3
Other Organics			
Benzene	2	--	< 1
Carbon tetrachloride	7	--	0.012
Dichloromethane	2	0.4*	0.3*
Hexachlorobenzene	2	< 0.01	0.01
PCBs	1	0.05	--
Pentachlorobenzene	2	< 0.01	< 0.01
1,2,3,4-Tetrachlorobenzene	2	< 0.01	< 0.01
1,2,3,5/1,2,4,5, Tetrachlorobenzene	2	< 0.01	--
1,2,3,-Trichlorobenzene	2	< 0.01	< 0.01
1,2,4-Trichlorobenzene	2	0.02	0.03
1,3,5-Trichlorobenzene	2	< 0.01	< 0.01
Toluene	2,5	0.1	2.8
Xylene	5	--	0.012

-- = Information not available.

* = Sample contamination suspected.

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Appendix 2

Local Board of Health **April 5, 1984**

A comparison of U.S., Canadian and Ontario drinking water standards with reference to the highest concentrations in treated Toronto drinking water (1971-83)

Substance (ppb)	U.S. drinking water standards		Canadian drinking water guidelines		Ontario drinking water objectives		Highest conc. in Toronto water 1971-83^a
	Primary MCL	Secondary MCL	MAC	OC	MAC	MDC	
Inorganics							
Antimony	-	-	-	<0.2	-	-	-
Arsenic	50	-	50	<5	50	-	3
Barium	1000	-	1000	<100	1000	-	520
Boron	-	-	5000	<10	5000	-	70
Cadmium	10	-	5	<1	5	-	10
Chloride	-	250000	250000	<250000	-	250000	300000
Chromium	50	-	50	<0.2	50	-	6
Copper	-	1000	1000	<1000	-	1000	145
Cyanide	-	-	200	<2	200	-	16
Fluoride	-	-	1500	1000/1200	2400	-	880
Iron	-	300	300	<50	-	300	20
Lead	50	-	50	<1	50	-	10
Manganese	-	50	50	<10	-	50	6
Mercury	2	-	1	<0.2	1	-	1.14
Nitrate (as N)	10000	-	10000	<1	10000	-	1900
Nitrite (as N)	-	-	1000	<1	1000	-	1900
Selenium	10	-	10	<2	10	-	7
Silver	50	-	50	<5	50	-	67
Sulphate	-	250000	500000	<150000	-	500000	30000
Sulphide (as H_2S)	-	-	50	<50	-	Inoffensive	-
Uranium	-	-	20	<1	20^b	-	3.2^c
Zinc	-	5000	5000	<5000	-	5000	64

Substance	U.S. drinking water standards		Canadian drinking water guidelines		Ontario drinking water objectives		Highest conc. in Toronto water 1971-83[a]
	Primary MCL	Secondary MCL	MAC	OC	MAC	MDC	
Organics							
Aldrin + Dieldrin	-	-	0.7	<0.00005	0.7	-	0.002
Carbaryl	-	-	70	<0.5	70	-	-
Chlordane (total)	-	-	7	<0.00005	7	-	-
DDT (total)	-	-	30	<0.00005	30	-	0.002
Diazinon	-	-	14	<0.001	14	-	-
Endrin	0.2	-	0.2	<0.00005	0.2	-	-
Heptachlor + Heptachlor epoxide	-	-	3	<0.00005	3	-	0.001
Lindane	4	-	4	<0.0001	4	-	0.002
Methoxychlor	100	-	100	<0.00005	100	-	-
Methyl Parathion	-	-	7	<0.001	7	-	-
Nitrilotriacetic acid	-	-	50	<0.2	-	-	-
Parathion	-	-	35	<0.001	35	-	-
PCBs	-	-	-	-	3[b]	-	-
Pesticides (total)	-	-	100	-	-	-	-
Phenols	-	-	2	<2	-	2	-
Toxaphene	5	-	5	<0.00005	5	-	-
Trihalomethanes	100	-	350	<0.5	350	-	41.3[d]
2,4-D	100	-	100	<1	100	-	-
2,4,5-TP (Silver)	10	-	10	<1	10	-	-

NOTES TO APPENDIX 2

Primary MCL

The primary maximum contaminant levels (MCL) regulate concentrations of contaminants in drinking water that affect, or could potentially affect, the public's health.

Secondary MCL

The secondary maximum contaminant levels (MCL) regulate concentrations of contaminants in drinking water that primarily affect the aesthetic qualities of that water.

MAC

Federal maximum acceptable concentrations (MAC) are guidelines established on either public health or aesthetic criteria. Provincial (Ontario) maximum acceptable concentrations (MAC) are established exclusively on public health criteria/

OC

Objective concentrations (OC) are established on both health and aesthetic criteria.

MDC

Maximum desirable concentrations (MDC) are established on aesthetic criteria only.

ppb

Parts per billion, equivalent to ug/L.

a - Data taken from Appendix 1.

b - Refers to the "interim maximum acceptable concentrations". These are established when the scientific data used to assess health hazards is subject to public and scientific debate.

c - This figure represents the highest uranyl ion (UO2) concentration.

d - This figure represents the highest chloroform concentration.

APPENDIX 3

Summary of the U.S. Safe Drinking Water Act, 1974

Under the Act the Environmental Protection Agency is responsible for establishing national standards, and the States are responsible for enforcing them and otherwise supervising public water supply systems and sources of drinking water.

The Act provides for:

- The setting of primary regulations for the protection of the public health;
- The setting of secondary regulations relating to the taste, odour and appearance of drinking water;
- Measures to protect underground drinking water sources;
- Aid to the States to improve drinking water programs;
- Citizen suits against any party believed to be in violation of the Act;
- Penalties to be levied against operators of a public water system, in certain circumstances, when they do not comply with the Act;
- Notice to be given to consumers of a public water supply when the water fails to meet a primary drinking water regulation or when the operator has failed to perform the required monitoring.
- Variances and exemptions to be granted from required contaminant levels.

At present the Act provides national interim regulations for 10 inorganic and six organic chemicals, bacteria, radioactivity, turbidity and total trihalomethanes (THM's). These regulations became effective in June 1977. The Environmental Protection Agency is also required to prescribe revised national regulations for substances that may adversely affect health, and these new regulations are currently being prepared.

APPENDIX 4

A4 An Epidemiological Study of Health Risks in Relation to Water Supplies in Toronto and Other Ontario Municipalities.

A4.1 Introduction

Although there have been many epidemiological studies of drinking water, no available studies have been reported on possible human health risks associated with water supplies from Lake Ontario. There have been concerns raised that the presence of numerous inorganic and synthetic organic chemicals in Lake Ontario, as well as the common use of chlorination in the treatment of drinking water supplies, potentially may present a health hazard. A preliminary attempt is made here to explore the question of possible human health risks associated with chronic ingestion of municipally-treated water supplied from Lake Ontario and the Great Lakes.

Data on cancers, adverse pregnancy outcomes and early deaths in several Ontario communities were examined for associations with the mutagenicity of their water supplies, to determine whether high rates of these health outcomes were associated with water of greater mutagenicity. In a second type of analysis, the health experience of the City of Toronto was compared to that of Ontario regarding cancer mortality.

Cancers of the gastrointestinal and urinary tracts (particularly colon, rectum and bladder), were examined because these sites have been associated consistently with high levels of water contaminants in previous studies (see Section 8). The long latency period for the development of most cancers constitutes a major limitation of this approach since water quality data are available only for recent times.

Health risks which probably would not be subject to a long latency period were considered also, i.e., adverse pregnancy outcomes and early deaths. Some studies have linked congenital central nervous system anomalies to soft water or the presence of nitrates in water, although these relationships have not been consistently demonstrated (see Section 8). Parental exposure to environmental chemicals and irradiation have been associated with increased rates of spontaneous abortion, stillbirth, and neonatal and childhood mortality, however, the exposures were not through drinking water (1,2).

A4.2 Methods

The water quality variables used in these analyses were measures of water mutagenicity. Measurements by Williams et al. (3) of Health and Welfare Canada were used to rank 11 Ontario municipalities, including Toronto, with respect to mutagenicity of their water supplies. Since different measures of mutagenicity led to different relative ranks, four sets of ranks were computed as shown in Table A1. Toronto's water had a relatively high overall mutagenicity.

Mortality counts for the communities were obtained from the Ontario Ministry of Health for 1973-1981. Gastrointestinal and urinary tract cancers were included because of their association with drinking water in previous studies. Mortality rates from lung cancer and transport accidents were considered for comparison purposes, as causes of death that would not be expected to be associated with drinking water.

Population counts for the communities were obtained from Statistics Canada 1976 and 1981 population figures (4). From these data, cause-specific, age-adjusted death rates for these municipalities were calculated by the direct method of applying age-specific death rates in the different municipalities to a standard population. The Ontario 1981 population was used as the standardized population (5).

A4.2.1 Mortality

Mortality data were aggregated for 1973-77 and 1978-81. Analyses of these data assume that there are no changes in population or mortality rates between 1973-77 and between 1978-81. In fact, 6 of the communities increased in population from 1973-81, and the population of 5 communities decreased. Only for Toronto (-16.1%) and Sarnia (-11.6%) were these changes greater than 10%, while Ontario's population increased 8.6% from 1973-81 (6). Death rates generally decreased between 1973-77 and 1978-81. For Ontario, each of the gastrointestinal and urinary tract cancers as well as total death rate decreased (a decline of 2-18%), while lung cancer increased in that time period. These changes in population and mortality rates make our age-adjusted mortality rates only approximate, and their impact upon individual analyses is difficult to predict.

A4.2.2 Adverse Pregnancy Outcomes

Data regarding stillbirths, neonatal mortality (<7 days) and infant mortality (<1 year) were obtained from the Ontario Vital Statistics of 1976 to 1980 (6). Annual counts of these parameters were adjusted by considering annual totals of live births in each municipality.

The Ontario Ministry of Health provided rates of congenital anomalies for 10 specific abnormalities, averaged over the period 1973-1981 (7). Congenital anomaly rates included both live births and stillbirths, and were available only for counties, not for individual municipalities. Four counties in which the study municipalities made up less than 25% of the population of the counties, were excluded from the analyses.

A4.3 Analysis

Correlation analysis was used to test for possible associations between health hazards and drinking water mutagenicity. The Statistical Analysis System (SAS) computer package was employed to calculate Spearman correlation coefficients. All four water mutagenicity rankings (See Table A1) were used in individual analyses for each outcome.

Eleven of the 12 municipalities investigated by Williams et al. were included in the analyses. Port Dover was excluded because it merged with several other communities in 1974 to form Nanticoke, and statistics on Port Dover alone were not available. All eleven remaining communities were included in the mortality analyses (i.e., cancers and early deaths). Only 7 municipalities were included in the analyses for congenital anomalies, since Amherstberg, Goderich, Leamington and Port Colborne made up only a small proportion of the county population. The data were analyzed for all communities together. Separate analyses were done for those communities where incidence of a health outcome in a community was 5 or more.

A second analytic approach compared Toronto's mortality rates with those of Ontario. Indirect standardization was employed, comparing observed deaths in Toronto from 1973-1977 and 1978-81 with the number expected if Toronto had experienced the age-specific death rates of Ontario in that time period. In this way, standardized mortality ratios (SMR's) were calculated, and their statistical significance was tested.

A4.4 Results and Discussion

A4.4.1 Cause-Specific Mortalities

Coefficients for correlations between age-adjusted death rates and overall water mutagenicity were computed using each set of mutagenicity ranks, with and without communities having fewer than 5 deaths. Examination of these coefficients revealed no consistent or meaningful patterns of association, and statistical probabilities were no better than chance. (see Table A2)

Due to uncertainties in the data (i.e., changes in population and mortality rates, lack of information on past mutagenicity, exposure of target groups) it cannot be determined whether the absence of effects represents a true lack of association between water mutagenicity and cancers (i.e., failure of the model) or limitations of the data and method.

These results give us confidence that water mutagenicity is not associated with large increases in cancer risk in Ontario; (even with the approximations in these data, large increases presumably would have been detected). On the basis of these analyses, however, we cannot dismiss the possibility of marginal increases in risk being associated with water mutagenicity.

A4.4.2 Early Deaths

Rates of stillbirth, neonatal mortality, and infant mortality were examined for correlation with overall water mutagenicity. Results are presented in Table A3. Stillbirths were uncorrelated with mutagenicity, but infant mortality was significantly correlated with overall water mutagenicity. Neonatal mortality showed the same trend. Similar positive associations between infant and neonatal mortality and water mutagenicity were observed when three other mutagenicity rankings were employed.

These findings are suggestive of a relationship between water quality and infant and neonatal mortality, but further investigation is needed before conclusions can be drawn. Causes of death should be separated in the analyses, and data on potentially confounding factors should be included if possible (e.g., parent's occupation, smoking and nutrition habits, infant nutrition, etc.). Information regarding birth weights would be useful, since low birth weight is often a risk factor in neonatal and infant mortality.

A4.4.3 Congenital Abnormalities

Since central nervous system birth defects have been tentatively linked to water supplies in some previous studies, we considered incidence rates of anencephalus, hydrocephalus and spina bifida in our investigation (8,9,10). There were no significant correlations of any of these birth defects with overall water mutagonicity, nor with the three other mutagenicity rankings considered.

No conclusion can be drawn from this result because of a major limitation of the data: birth defects data were aggregated at a county level while mutagenicity was measured at a municipal level. Even though 4 counties were excluded where the municipalities represented less than 25% of the county population, we do not know, nor can we assume that the remaining 75% of the population in the other counties drew their water from the water supplies of the target municipalities. In order to conclude that no relationship exists between congenital anomalies and water mutagenicity, at a minimum data would have to be obtained on mutagenicity of all drinking water supplies in a county, or birth defects would have to be aggregated at a municipal level. Additionally the influence of potentially confounding factors would have to be controlled or accounted for.

A4.4.4 Comparison of Death Rates for the City of Toronto with Ontario

Standardized mortality ratios (SMR's) were computed comparing death rates in Toronto with Ontario.

When the limitations and approximations in the data are taken into consideration, this analysis represents only a rough comparison of Toronto with Ontario. If large differences in death rates were present, these probably would be reflected in the SMR's, whereas small differences would likely remain undetected. Conversely, large SMR's probably represent real differences in death rates, whereas smaller (perhaps statistically significant) values may result from inaccuracies caused by approximations.

Initial comparisons indicated that males in Toronto had a higher death rate from stomach, gastrointestinal, lung and all cancers and all causes than in Ontario as a whole, while their rate of transport accidents was lower. However, some approximations in the data resulted in inflated mortality rates for Toronto (e.g., estimates of respective population changes over time; increases in City of Toronto rates due to inclusion of non-residents claiming to be residents).

Firstly, cause-specific deaths for 1973-77 were summed, and deaths for 1978-81 were also summed. Rates were calculated from numbers of deaths by dividing 1973-77 data by the 1976 census counts of the population, and 1978-81 data by 1981 populations. The difficulty with the data arose because Ontario's population increased from 1973-81, whereas Toronto's population decreased in that time. If these population changes were evenly divided among males and females of all age groups, this difference alone would account for an SMR of 1.06 for 1973-77, and 1.03 for 1978-81.

A second factor that acted to increase Toronto's apparent death rate was the listing in the Ontario Vital Statistics of some people living outside the City of Toronto as City residents. When each address is individually checked, approximately 4% of persons listing Toronto as their address do not reside in the City of Toronto. This would increase SMR's by 0.04.

When these approximations are taken into consideration, only death rates from stomach cancer in males and transport accidents in both sexes appear to differ substantially between Toronto and Ontario. Stomach cancer has been associated infrequently with drinking water in previous studies. Sites which have been found to exhibit higher cancer mortality rates in previous research do not differ substantially between Toronto and Ontario. Rectum, colon and bladder cancer mortality rates were not significantly elevated in Toronto. This suggests there is no major increase in cancer risk associated with water supplies in Toronto. However, it should be noted that these preliminary comparisons would not detect small differences.

Rates of stillbirths, neonatal deaths and infant deaths were also similar when Toronto and Ontario rates were compared.

A4.5 Conclusions

Studies in several regions of the United States have reported possible associations between cancer of the colon, rectum, bladder (and to a lesser extent) stomach, and water contaminants, particularly trihalomethanes (see Section 8). We determined death rates caused by these cancers for eleven Ontario municipalities, including Toronto. These rates were tested for association with water quality, measured as water mutagenicity rank. Adverse pregnancy outcomes and early deaths were also considered.

The data showed no evidence suggesting that cancer mortality rates are associated with water mutagenicity in Ontario (this assumes mutagenic activity has not changed for several decades).

Infant mortality rates were found to be positively correlated with water mutagenicity, i.e., higher rates of infant mortality were associated with water of greater mutagenicity. It is not clear whether this statistical correlation reflects a real association between water quality and infant death rates, or whether lack of adjustment for confounding factors is responsible for the apparent relationship.

No significant associations between central nervous system congenital anomalies and water mutagenicity were demonstrated.

In a second analysis, mortality rates were compared between the City of Toronto and Ontario. Mortality rates for colon, rectal, bladder and stomach cancer were compared, because these cancers have been associated with water contamination in other parts of the world. These comparisons indicated no differences in rates of colon, rectum and bladder cancer mortality in the two populations. Thus, no increase in cancer mortality was demonstrated to be associated with Toronto's drinking water. Small differences in cancer mortality risk which may have been undetected due to problems with the data and mothod, cannot be dismissed at this time.

On the basis of this exploratory analysis of the association between water mutagenicity and health we would recommend that future epidemiological research on this subject focus on short-term outcomes, such as adverse pregnancy outcomes and possibly congenital anomalies. Research efforts should be designed to detect small changes in morbidity and mortality rates. In particular, it is important to ascertain that the population base for outcomes corresponds to the exposed populations (i.e., those using the same water supply). Because the outcomes of interest are so prone to influence of other factors, such as parents' smoking, dietary habits, occupation, use of drugs and alcohol, mother's age, socioeconomic status, etc., the ideal data base for birth outcomes would be hospital records, which contain most of the pertinent information. In addition, outcomes such as birth weight, cause of death, infant feeding habits, etc., should be examined to suggest possible causal relations if increases are found.

References to Appendix 4

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Table A1

Water Mutagenicity Ranks for Selected Ontario Municipalities

	Water mutagenicity ranks[2]			
Municipality & Water Source[1]	Overall Rank[3]	Summer Rank[3]	Category by Slope[4]	Category by no. of Revertants[4]
Sault Ste. Marie St. Mary's River	1	1	1	1
Kingston Lake Ontario	2	2	1	1
St. Catharines Lake Erie	3	5.5	2	2
Thunder Bay Lake Superior	4	3	2	1
Amherstburg Detroit River	5.5	7	2	3
Sarnia St. Clair River	5.5	8	2	2
Leamington Lake Erie	7	10	2	3
Owen Sound Georgian Bay	8	4	3	2
Toronto Lake Ontario	9	5.5	3	1
Goderich Lake Huron	10	10	3	3
Port Colborne Lake Erie	11	10	3	3

1: Water treatment practices are summarized in Williams et al. (1982).

2: Based on mutagenicity determinations published by Williams et al. (1982).

3: A rank of 1 is the least mutagenic, while a rank of 11 is relatively mutagenic.

4: Category 1 is the least mutagenic, while category 3 is relatively mutagenic.

The measurement of mutagenicity

Mutagenicity of water samples was determined in the Ames test. This technique shows the mutational response of host bacteria to substances which may have the tendency to induce mutations in the genetic material. Usually, Salmonella bacteria are chosen, sometimes in combination with a rat liver extract, called S9 (which enables indirect mutagens to be detected). Previously mutated strains are used, so that if mutational events occur, the bacteria "revert" to their unaltered form. Thus, the maximum number of mutants, or "revertants", per ug of the substance under investigation, are usually measured.

Since different measurements led to different ranks, we calculated four sets of ranks based on different criteria, as follows:

Overall rank: Mutagenicity ranks for slope and maximum number of revertants, summer and winter, were averaged for each community.

Summer rank: Only summer data were considered. Ranks for slope and maximum number of revertants were averaged for each community.

Categories based on slope: Three categories were used - high (slope 6 el for both summer and winter); medium (slope >1 for one season only); and low (slope >1 for both summer and winter).

Categories based on maximum number of revertants: The maximum number of revertants (summer or winter) for each water supply was categorized as low (<600), medium (600-800), or high (>800).

Table A2

Age-Adjusted Death Rates and Correlation Coefficients for Selected Causes of Death with Overall Water Mutagenicity

Cause of death	Correlation Coefficient[1]		Annual Ontario Rate per 100,000[2]	
	M	F	M	F
Stomach Cancer	0.19	0.32	11.8	7.0
Colon Cancer[3]	-0.65*	0.42	6.0	7.1
Rectum Cancer	0.28	-0.01	7.6	5.4
Gastrointestinal Tract Cancer	-0.50	0.45	56.0	47.9
Bladder Cancer	-0.40	-0.15	6.4	2.8
Urinary Tract Cancer	-0.61*	0.19	10.4	5.0
Lung Cancer	-0.47	-0.48	56.1	14.2
Total Cancer	-0.41	0.65	181.7	146.3
Transport Accidents	0.39	0.15	32.0	11.2
Total Causes	-0.21	0.05	862.1	664.6

[1] Spearman correlation coefficient of age-adjusted death rates for 1973-81, versus overall water mutagenicity rank, n=11.

[2] Data for 1973-1981.

[3] Data for 1973-1977 only.

*: p<.05

Table A3

Age-Specific Death Rates and Correlation Coefficients for Early Deaths with Water Mutagenicity

Age category at death	Correlation coefficient[1]	Annual Ontario Rate per 1,000 live births[2]
Stillbirth	0.15	8.5
Neonatal (<7 days) mortality	0.56	6.5
Infant (<1 year) mortality	0.67*	10.9

[1] Spearman correlation coefficient of mortality rates for 1976-1980, versus overall water mutagenicity rank, $n=11$.

[2] Data for 1976-1980.

*: $p<.05$

APPENDIX 5

Alternatives for Drinking Water Disinfection and Their Limitations as Considered by the Safe Drinking Water Committee of the U.S. National Research Council[1].

Disinfecting Agent	Limitations
Chlorine	Efficacy decreases with decreasing pH; affected by ammonia or organic nitrogen; formation of trihalomethanes.
Ozone	On-site generation required; no residual; other disinfectant needed for residual.
Chlorine dioxide	On-site generation required; interim "maximum contaminant level" set at 1 mg/L by EPA.
Iodine	Biocidal activity sensitive to pH.
Bromine	Lack of technological experience; activity may be pH sensitive.
Chloramine	Mediocre bactericide; poor virucide.
Ferrate	Moderate bactericide; good virucide; unstable residual; lack of technological experience.
High pH conditions	Poor biocide.
Hydrogen peroxide	Poor biocide.
Ionizing radiation	Lack of technological experience.
Potassium permanganate	Poor biocide.
Silver	Poor biocide; "maximum contaminant level" set at 0.05 mg/L.
U.V. light	No residual; use limited by equipment maintenance considerations.

[1] Adapted from Drinking Water and Health, Volume 2, 1980.

APPENDIX 6

GLOSSARY

adsorption	adherence of substances to a porous surface (e.g., GAC)
adipose	of a fatty nature
aggressivity	corrosive potential of drinking water
Ames test	a biological test to determine if a substance can cause mutations
bioaccumulate	to collect in living (esp. animal) tissue
biodegradable	capable of being broken down, particularly into harmless products by microorganisms
biocidal	destructive to living organisms
carcinogenicity	quality of a substance referring to its cancer initiating or promoting ability
coliform count	number of fecal coliform bacteria
DDT	dichlor diphenyl trichloroethane
dioxins	family of organic chemicals
DOC	dissolved oxygen content
EPA	(United States) Environmental Protection Agency
GAC/PAC	granular activated carbon, powdered activated carbon
IJC	International Joint Commission
inorganic	composed of matter other than hydrogen and carbon atoms, usually a mineral or a metal
isotopes	different forms of the same chemical element
in vitro	occurring in a culture medium

in vivo	occurring in a living organism
metabolites	substance which takes part in the chemical interactions of a living organism
MGD	million gallons per day
mutagenicity	quality of a substance referring to its ability to alter genetic material
neoplasms	benign tumors
NRC/NAS	National Research Council/National Academy of Science
organic	containing hydrogen and carbon atoms usually related to a living organism
PCB	polychlorinated biphenyls
phenols	a family of organic chemicals
pH	quality of water characterizing level of acidity and alkalinity
polyaromatic hydrocarbons	organic compounds composed of two or more fused carbon rings
synergistic	capacity to produce a cooperative action of discrete agencies, such that the total effect is greater than the sum of the two effects taken independently
TCDD	tetrachlorinated dibenzo p dioxin
teratogenicity	quality of a substance referring to its ability to cause abnormal development
trihalomethanes	organic compounds formed by chlorination of organic matter
turbidity	quality of water characterizing the amount of suspended solids present
volatization	evaporation of certain organic compounds